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AN EVALUATION OF COMPOSITE TEFLON-ALUMINUM FOIL BLADDERS FOR THE SURVEYOR VERNIER PROPULSION SYSTEM

2 March 1967/SSD 78020

Performed in response to
JPL Change Order No. 119, dated 13 May 1966

JPL CONTRACT NO. 950056

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

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ABSTRACT

The Surveyor vernier propulsion system operates on MON-10 and MMH-hydrate propellants. During the mission, the present Teflon bladders which contain the propellants allow the helium pressurant gas to permeate at a rate such that the propellants are saturated prior to spacecraft terminal descent.

The results of a comprehensive engineering evaluation of composite Teflon-aluminum foil bladders for the Surveyor vernier propulsion system are presented. The primary purpose of the program was to determine the effectiveness of the aluminum foil as a helium permeation barrier.

The test program covered helium and nitrogen permeation, vibration and propellant exposure effects, expulsion life, propellant permeation, physical properties tests, and development of improved bladder installation techniques. Estimates of the effect of propellant saturation fraction on spacecraft stability parameters are presented.

PREFACE

The selection of bladder material for this test program was based, in part, on measurements of relative rates of helium permeation through small specimens of several proposed materials (see footnote, p. 4-1) using laboratory apparatus in which one side of the test specimen was in contact with oxidizer (MON-10) and the opposite side was exposed to helium at 800 psi. Permeation rate was determined by measuring the helium content of the oxidizer at the end of 20 hours.

While such tests provide an economical method for selection of material, it is evident that the gas permeation rate measured on a small specimen of a given material cannot be readily extrapolated to predict performance of a full size bladder unless the ratio of bladder area to propellant volume, and the ratio of foil area to total area, have been carefully simulated. Even then, the extrapolation is likely to produce an erroneous prediction. In the present report, therefore, the helium and nitrogen permeation results (Sec. 8) are based entirely on tests of full-size bladders properly loaded with propellant.

Measurements of "outward permeation" of propellants through the bladder material (Sec. 6), however, were made only on small specimens, and are intended primarily to provide qualitative evaluation of the effectiveness of the aluminum foil as a barrier to propellant permeation.

H. C. Thorman
JPL, April 1967

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1. INTRODUCTION

The Surveyor vernier propulsion system consists of three throttleable bipropellant liquid rockets having thrust ranges of 30 to 104 pounds. The rockets are mounted just inboard of the attachment points of the three spacecraft extendable landing legs. The propellants are MON-10 (mixed oxides of nitrogen, 90 percent N_2O_4, and10 percent NO) and MMH-hydrate (monohydrate of monomethyl hydrazine).

The propellants are contained within flexible Teflon bladders mounted in thin-walled titanium tanks, and are positively expelled by collapsing the bladders. After propellants are loaded in preparation for a mission, the ullage space above the bladders is pressurized with helium to approximately 240 psig. This pressure is referred to as the "pad pressure." During the nominal 17-day prelaunch period and the approximate 16-hour premidcourse part of the mission, the helium permeates through the bladder and saturates the propellant at pad pressure. Just prior to the midcourse correction maneuver, the bladders are pressurized for the last 50 hours of the mission. During this time, further permeation takes place, resulting in nearly saturated propellants prior to terminal descent.

A significant part of the terminal descent phase of the mission is carried out at low thrust, during which time the pressure drop through the engine throttle valves is greatest. If the propellants are partially or fully saturated with helium, the large quantities of gas coming out of solution and the resulting two-phase flow which occurs decreases the dynamic response of the vernier engines. Although the response is still well within the required range, for all expected flight conditions it was desirable to improve the response for some nonstandard operating conditions.

The use of a composite Teflon-aluminum bladder (hereafter called the metallized bladder) as a means of reducing pressurant gas permeation into Surveyor vernier propulsion system propellants was first investigated at Hughes in 1965 when two metallized bladders were subjected to permeation and expulsion tests (Appendix A). The results of these initial tests were encouraging. The permeation rate for helium into MON-10 was found to be reduced 30 times for the metallized as opposed to the all-Teflon bladder. Expulsion efficiency appeared adequate.

Tests of metallized bladders for the Lunar Orbiter spacecraft early in 1966 (Reference 1) indicated that the foil layer was an effective permeation barrier against nitrogen pressurant gas. Based on these encouraging initial results, JPL Change Order 119 to the Surveyor Program directed Hughes Aircraft Company to undertake a comprehensive engineering evaluation of the metallized bladder. Sixteen bladders were procured for this effort. The test program covered gas permeation, propellant permeation, propellant exposure and expulsion life, vibration, physical properties determination, spacecraft stability analyses, and development of improved installation techniques. A major goal was to demonstrate a reduction of gas in the propellants of at least 65 percent at terminal descent from the nearly full saturation with the all-Teflon bladder.

2. SUMMARY

The results of a comprehensive engineering evaluation of metallized bladders for the Surveyor vernier propulsion system are presented in this report. The test program covered gas permeation, propellant permeation, propellant exposure and expulsion life, vibration, physical properties determination, and development of improved bladder installation techniques. Sixteen bladders were procured for this effort, of which 13 were subjected to one or more types of tests.

The bladders used in the program were a sandwich construction (inside-to-outside) of TFR, FEP, coated 1/4-mil aluminum foil (primer plus FEP), and FEP. All bladders delivered contained blisters and gas bubbles in the TFE layer beneath the aluminum foil. They were accepted as the best that could be fabricated under the existing state of the art after a prolonged vendor effort to perfect a process that would eliminate the blisters.

The more important results of the test program are summarized below.

PHYSICAL CHARACTERISTICS

The physical properties (tensile strength, modulus or elasticity, and density) of metallized bladder samples were inferior to those of the all-Teflon bladder. Tensile strength values ranged from 1.41 to 2.44 $\times 10^3$ psi, modulus of elasticity from 0.75 to 2.07 $\times 10^5$ psi, and specific gravity from 1.44 to 1.86. Corresponding values for all-Teflon samples were typically 4.4 $\times 10^3$, 0.70 $\times 10^5$, and 2.15, respectively. Modest deterioration occurred in all properties after exposure to referee fluids and propellants.

PROPELLANT PERMEATION

Permeation of MON-10 and MMH-hydrate through metallized bladder material was more than an order of magnitude lower than through all-Teflon material. MMH-hydrate permeability of the metallized material was below measurable levels.

GAS PERMEATION

The most significant result of the program was the failure of the metallized bladder to give the desired permeation resistance after FAT vibration or propellant exposure. The best result obtained with a new bladder was a saturation level of 53 percent at terminal descent, representing a 47 percent reduction over the full saturation that occurred with the all-Teflon bladder. Thus, the design objective of 65 percent gas reduction was not achieved even by using a bladder not exposed to either propellants or FAT vibration.

SPACECRAFT STABILITY IMPROVEMENT

The 47 percent gas reduction achieved with a new bladder would afford only modest increases in flight control phase margin and none at all in flight control gain margin. There would be no improvement in either gain or phase margin with bladders subjected to vibration or propellant storage.

PROPELLANT EXPOSURE AND EXPULSION

Of the eight bladders subjected to propellant exposure and expulsion tests, only three successfully completed the series of four standard qualification expulsions requiring 90 percent expulsion efficiency at 100, 70, and 0° F, followed by 99 percent at 0° F. The three bladders completing the expulsion series were fuel bladders. The five oxidizer bladders experienced failures of various sorts after one to three expulsions. From the general condition of the bladders after test, it is apparent that exposure to oxidizer is much more detrimental than exposure to fuel.

INSTALLATION PROCEDURES

A significantly improved installation technique, employing a specially designed insertion tool and collapse fixture, was developed.

3. PROGRAM SCOPE AND BLADDER TEST HISTORY

The test program was set up to develop or demonstrate the following:

1) A trouble-free bladder/tank assembly-insertion technique

2) Bladder capability to withstand Surveyor flight acceptance test (FAT) and type approval test (TAT) vibration

3) Three-months referee fluid and 1-month propellant exposure compatibility

4) Durability of at least three cycles of 90 percent, plus one cycle of 99 percent expulsion with propellants

5) Reduction in pressurizing gas permeation to meet a goal of 35 percent saturation or less at terminal descent.

6) Significantly reduced propellant permeation

7) Improvement of spacecraft stability margin by reduction of dissolved gas in the oxidizer.

All bladder tests were carried out using Surveyor flight-type hardware. Figure 3-1 is a sketch of the Surveyor tank-bladder-standpipe assembly, and Figure 3-2 is a photograph of a tank, standpipe, and an all-Teflon bladder. Surveyor propellants and referee fluids are:

Oxidizer:	MON-10 (mixed oxides of nitrogen, 90 percent N_2O_4, and 10 percent NO)
Fuel:	MMH-hydrate (monohydrate of monomethyl hydrazine)
Oxidizer referee fluid:	Genesolv D, electronic grade
Fuel referee fluid:	Isopropyl alcohol, mil-spec grade

Table 3-1 outlines the test program, and Table 3-2 gives the test history of each bladder.

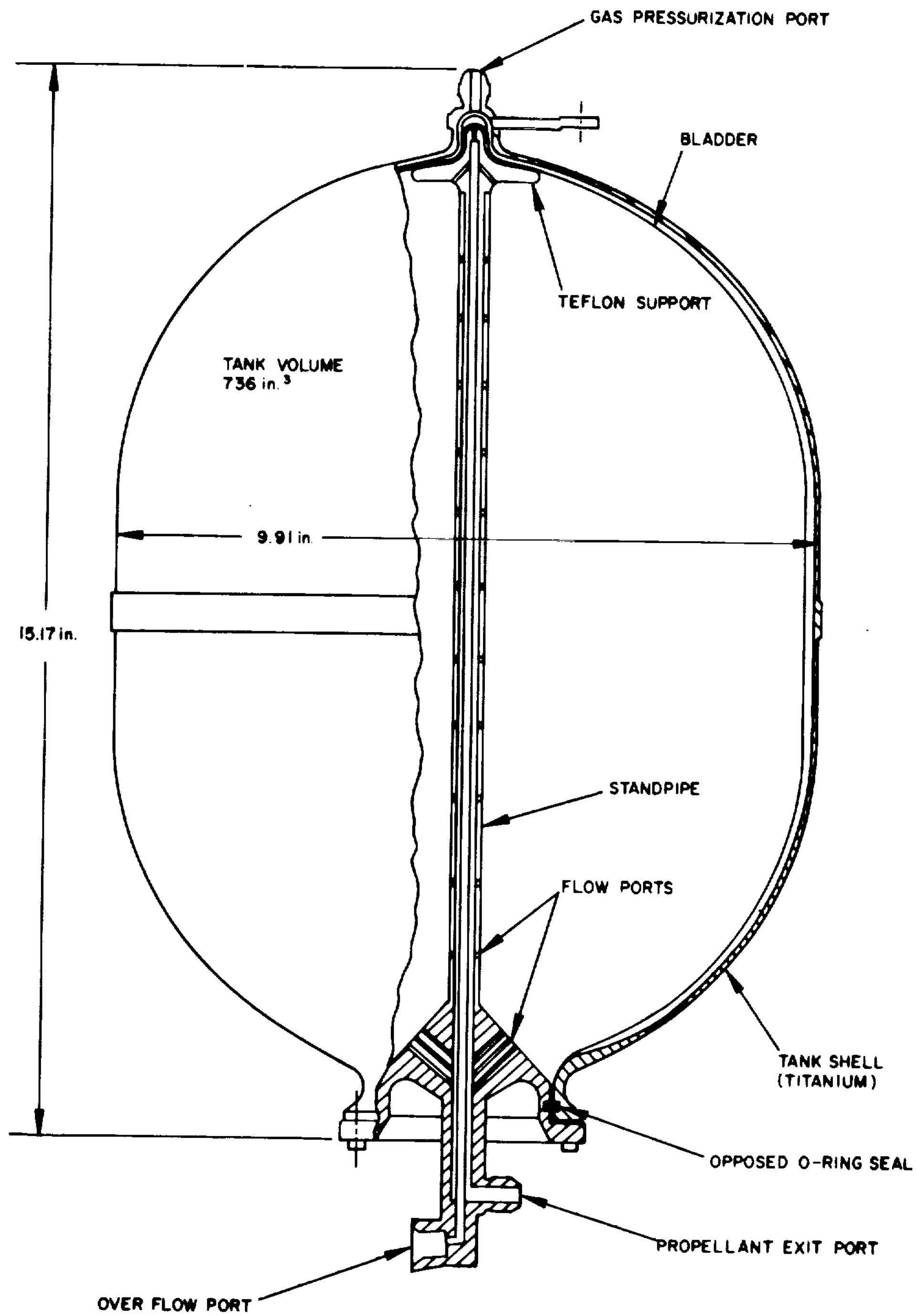

Figure 3-1. Surveyor Propellant Tank Assembly

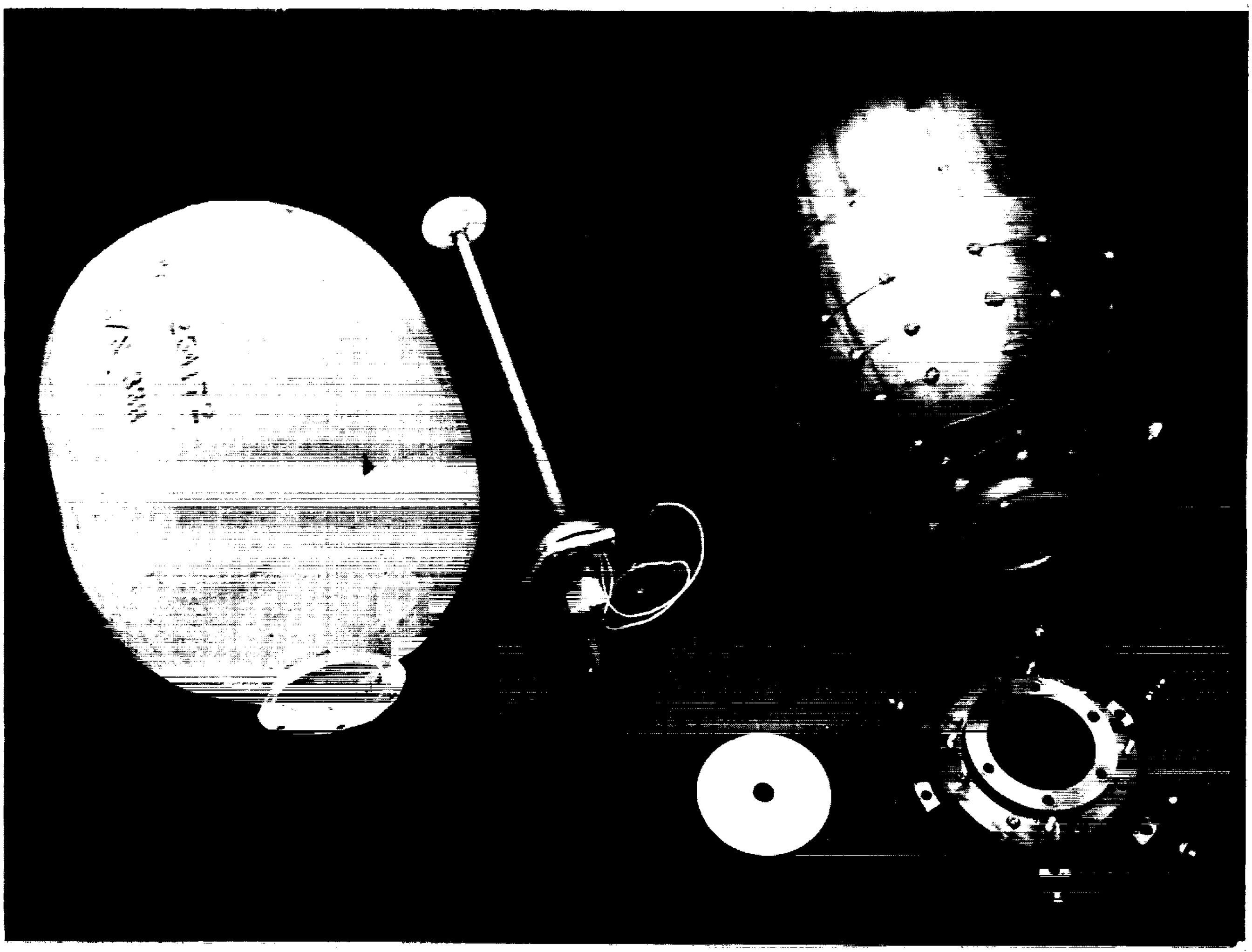

Figure 3-2. Propellant Tank Components
(Photo A13316)

TABLE 3-1. TEST PROGRAM SUMMARY

Bladder	Vibration	Referee Fluid Storage, 3 months,	Propellant Storage,* hours	Helium Permeation	Nitrogen Permeation	Expulsion
1	–	Genesolv D	Oxidizer, 96	–	–	Yes
2	–	Isopropyl alcohol	Fuel, 144	–	–	Yes
3	FAT and TAT with Genesolv D**	–	–	–	–	No
3A	FAT and TAT with Genesolv D	–	Oxidizer, 582	Oxidizer at 240 and 800 psig	Oxidizer at 240 psig	Yes
4	FAT and TAT with isopropyl alcohol**	–	–	–	–	No
4A	FAT and TAT with Genesolv D	–	–	Fuel at 240 psig	–	No
4B	–	–	Fuel, 570	Fuel at 800 psig	Fuel at 220 psig	Yes
5	–	–	Oxidizer, 1400	Oxidizer at 240 and 800 psig	Oxidizer at 240 psig	Yes
6	–	–	Oxidizer, 360	–	–	Yes
6A	–	–	Oxidizer, 870	Oxidizer at 240 and 800 psig	–	Yes
7	–	–	Fuel, 360	–	–	Yes
8	–	–	–	Oxidizer at 240 and 800 psig	–	No
9	Used for developing improved insertion technique					

*Includes gas permeation tests.

**These bladders were to be tested further but failed during vibration.

TABLE 3-2. BLADDER TEST HISTORY

Bladder 1 (Hughes S/N 418)	–	1) Three-months storage in Genesolv D at 70° F 2) Ninety-six-hours storage in oxidizer at 70° F 3) Expulsion tests with oxidizer at 100, 70, and 0° F, all 90 percent expelled
Bladder 2 (Hughes S/N 421)	–	1) Three months storage in isopropyl alcohol at 70° F 2) One hundred forty-four-hours storage in fuel at 70° F 3) Expulsion tests with fuel at 100, 70, and 0° F, all 90 percent expelled, and 0° F with 99 percent expelled
Bladder 3 (Hughes S/N 404)	–	FAT and TAT vibration with Genesolv D (failed)
Bladder 3A (Hughes S/N 438)	–	1) FAT and TAT vibration with Genesolv D 2) 240 psig helium permeation into oxidizer (24 hours) 3) 240 psig nitrogen permeation into oxidizer (168 hours) 4) 800 psig helium permeation into oxidizer (voided) 5) 800 psig helium permeation into oxidizer (66 hours) 6) 240 psig helium permeation into oxidizer (58 hours) 7) Expulsion test with oxidizer at 100° F with 90 percent expelled
Bladder 4 (Hughes S/N 436)	–	FAT and TAT vibration with Genesolv D (failed)
Bladder 4A (Hughes S/N 448)	–	1) FAT and TAT vibration with isopropyl alcohol 2) 240 psig helium permeation into fuel (312 hours)
Bladder 4B (Hughes S/N 437)	–	1) 220 psig nitrogen permeation into fuel (168 hours) 2) 800 psig helium permeation into fuel (66 hours) 3) Expulsion tests with fuel at 100, 70, and 0° F, all 90 percent expelled, and 0° F with 99 percent expelled
Bladder 5 (Hughes S/N 445)	–	1) 240 psig helium into oxidizer (336 hours) 2) 240 psig nitrogen into oxidizer (290 hours)

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Table 3-2 (continued)

		3) 240 psig helium into oxidizer (162 hours) 4) 800 psig helium into oxidizer (66 hours) 5) 800 psig helium into oxidizer (66 hours) 6) Expulsion test with oxidizer at 100° F, with 90 percent expelled
Bladder 6 (Hughes S/N 447)	–	1) Three hundred sixty-hours storage in oxidizer at 70° F 2) Expulsion tests at 70 and 0° F, both 90 percent expelled
Bladder 6A (Hughes S/N 423)	–	1) One hundred ninety-two-hours storage in oxidizer at 70° F 2) 240 psig helium permeation into oxidizer (240 hours) 3) Two hundred forty-hours storage in oxidizer at 70° F 4) 800 psig helium permeation into oxidizer (66 hours) 5) 240 psig helium permeation into oxidizer (58 hours) 6) Expulsion tests at 100 and 70° F, both 90 percent expelled, and 0° F with 98.3 percent expelled
Bladder 7 (Hughes S/N 428)	–	1) Three hundred sixty-hours storage in fuel at 70° F 2) Expulsion tests at 70, 0, and 100° F, all 90 percent expelled, and two tests at 0° F with 99 percent expelled
Bladder 8 (Hughes S/N 439)	–	Combination 240 and 800 psig helium permeation into oxidizer (270 hours)
Bladder 9 (Hughes S/N 444)	–	Used for developing improved insertion techniques

4. BLADDER CONSTRUCTION AND PHYSICAL CHARACTERISTICS

BLADDER CONSTRUCTION

The metallized bladders used in the present program are a sandwich construction of the following materials (inside to outside):

3 mils – TFE (tetrafluorothylene)

1 mil – FEP (fluorinated ethylene propylene)

1 mil – "Double-dip" Teflon-coated aluminum foil (actual foil thickness is 1/4 mil)

2 mils – FEP

The coated foil (1/4 mil of 1145 alloy) used in these bladders* is first dipped in a TFE primer solution, cured briefly at 700° F, and then dipped in the FEP dispersion, after which the FEP is cured at 580° F. (Hence the term "double dip;" if no primer is used, the foil layer is termed "single dip.")

The Dilectrix process for fabricating Teflon bladders is described fully in Reference 2. The major modification for manufacturing metallized bladders involves the coated foil layup and lamination procedure.

Bladder construction begins with a thin aluminum mandrel. Teflon, in the form of an aqueous dispersion, is sprayed on a slowly rotating mandrel. The 3-mil TFE layer is built up of several sublayers, each about 0.3-mil thick. Each 0.3-mil coat is cured in an oven at 670° F. After the desired 3 mils are achieved, the 1-mil FEP layer is built up in a similar manner, except that the layers are cured at 570° F.

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*Helium permeation tests early in 1965 on 2-inch diameter samples of various proposed bladder materials had indicated practically no difference in permeation resistance between 1/4-mil and 1/2-mil foil. Thus, 1/4-mil foil was selected because of its greater flexibility.

Figure 4-1. Completed Bladder
(Photo A15631)

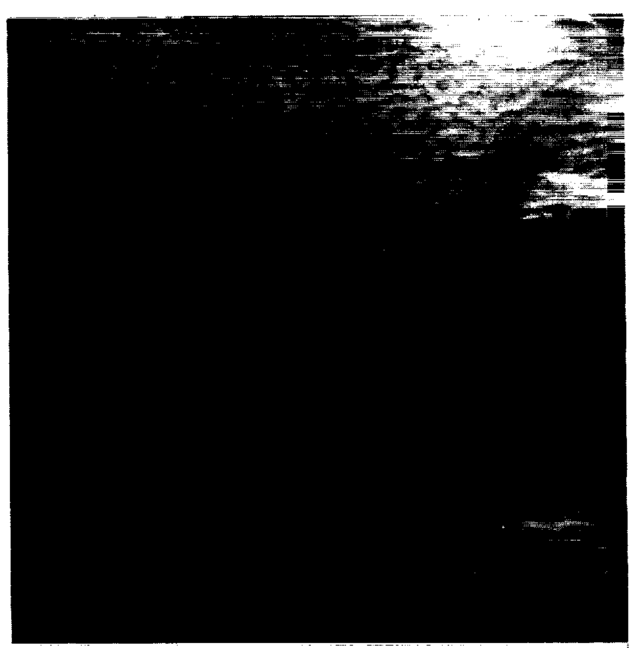

Figure 4-2. TFE Side of Bladder Material
(Photo A15911)

The coated foil is laid up over the 1-mil FEP layer. The foil is formed to the surface and trimmed as necessary to obtain at least a one-half inch overlap at the joints. A vacuum bag technique is employed in attaching the coated foil to the FEP layer. Vacuum is held for 1 hour, after which the assembly is cured. After removal of the vacuum bag, the FEP outer layer is built up. Each layer is cured at 550° F. No foil is applied to the nipple or flange. A completed bladder is shown in Figure 4-1.

In the fabrication process of bladders for this program, blisters began to form under the foil after bonding of the foil layers. The blisters increased in size and number as each sublayer of outer FEP was cured. Upon bladder completion, the blisters typically covered a significant portion of the surface. Figure 4-2 shows the appearance typical of the TFE side of the bladder. The light colored areas are blisters, many of which have joined to form irregular patterns. Microscopic examination of a sectioned sample indicated most of the blisters were located in the 1-mil FEP layer.

Several variations in the processing technique were tried in an attempt to eliminate the blisters. Only slight improvements were obtained, and these depended upon the particular foil lot used. Dilectrix has produced relatively blister-free metallized bladders through use of a single-dip coated foil, i.e., the TFE primer dip is eliminated and the foil is dipped only in FEP.* Thus, the problem would appear to be associated with the double-dipped foil (primer coat plus FEP coat).

In establishing the requirements for bladder construction in the current program, both single- and double-dip foil were considered. Tests conducted on small preproduction metallized samples immersed in MON-10 showed that those fabricated with double-dip foil were unaffected, whereas samples fabricated with single-dip foil exhibited delamination of the Teflon layers from the foil layer. The double-dip foil was selected primarily because of its better performance in these tests.

PHYSICAL CHARACTERISTICS PROGRAM

Test Procedure

Extensive tests were carried out to determine the physical characteristics of the metallized bladder material. The test material was divided into three groups. Groups I and II each consisted of four 6 by 20-inch sheets of material constructed on cylindrical mandrels. Group III consisted of ten 6 by 20-inch sheets fabricated concurrent with fabrication of ten actual bladders, i.e., for each of the ten bladders a 6 by 20-inch sheet was subjected to an identical fabrication process. Test specimens were cut in numbers and sizes as follows:

*The bladders referred to in Reference 1 were constructed of this type foil.

Groups I and II (from each group):

89 pieces — 4 by 1/4 inch for tensile strength tests

89 pieces — 6 by 1/4 inch for modulus tests

39 pieces — I by 1 inch for density tests

Groups III bladder material (from each of the 10 sheets):

20 pieces — 4 by 1/4 inch for tensile strength tests

20 pieces — 6 by 1/4 inch for modulus tests

12 pieces — 1 by 1 inch for density tests

The test specimens were immersed in one of the following for 66, 336, and 720 hours: 1) isopropyl alcohol, 2) Genesolv D, 3) fuel, and 4) oxidizer. From each set of Groups I and II and from each sheet of the Group III bladder material, five specimens 4 by 1/4 inch, five specimens 6 by 1/4 inch, and three specimens 1 by 1 inch were control specimens exposed to no fluid but tested under standard laboratory conditions. At the end of each exposure period, the test specimens were allowed to dry at ambient conditions for 24 hours before testing. Test specimens from Groups I and II exposed to Genesolv D and to alcohol were also tested for tensile strength and for modulus in a wet condition, i.e., within 2 hours after removal from the fluid. From the bladder material, the specimens from two sheets were tested for tensile strength and for modulus in the wet condition after immersion in Genesolv D. The density tests were performed in accordance with ASTM D297, while the tensile strength and the modulus tests were performed in accordance with ASTM D882.

Test Results

Test results are summarized in Table 4-1. Firm conclusions from the physical properties data are difficult to establish because of the rather large variability in the data. For example, the average modulus of elasticity for the bladder 5 control samples was 1.95×10^5 psi, but the values of the five samples ranged from 1.34 to 2.29×10^5 psi. This rather wide scatter is believed due to the blisters in the composite material. Even though the blisters make precise interpretation difficult, some general trends can be discerned.

Tensile strength results for the control samples test are compared to those after 720 hours of fluid storage for the Group III material (Figure 4-3). It is clear that a 10 to 20 percent loss of tensile strength occurs after fluid storage, and that Genesolv D gives about the same drop as fuel and oxidizer. Figure 4-4 shows the same comparison for modulus of elasticity. Here the results are less uniform, but the increase in modulus after propellant storage is evident, especially for fuel. The data for the intermediate storage periods showed too great a variability to allow firm conclusions as to whether storage effects depend to any significant extent on the total exposure time.

TABLE 4-1. PHYSICAL PROPERTIES OF BLADDER MATERIAL

Group	Serial Number	Exposure, 720 hours	Average Tensile Strength, psi $\times 10^3$	Average Modulus of Elasticity, psi $\times 10^5$	Average Specific Gravity
I		None	1.89	1.00	1.86
		Fuel	1.72	1.89	1.76
		Oxidizer	1.83	2.00	1.79
		Isopropyl alcohol	1.96	1.04	1.81
		Isopropyl alcohol (wet)	2.12	1.13	–
		Genesolv D	2.23	0.94	1.90
		Genesolv D (wet)	2.10	1.17	–
II		None	1.41	1.21	1.44
		Fuel	1.44	1.12	1.51
		Oxidizer	1.51	0.93	1.48
		Isopropyl alcohol	1.45	2.06	1.34
		Isopropyl alcohol (wet)	1.69	0.88	–
		Genesolv D	1.10	1.85	1.59
		Genesolv D (wet)	1.39	0.82	–
III	428	None	2.07	1.20	1.76
		Oxidizer	1.78	2.07	1.91
	440	None	2.44	1.27	1.66
		Oxidizer	2.03	1.76	1.87
	418	None	2.19	0.76	1.79
		Fuel	1.57	1.67	1.71
	421	None	2.18	0.76	1.79
		Fuel	1.73	1.99	1.81
	436	None	2.08	0.89	1.70
		Genesolv D	1.55	1.53	1.65
	404	None	1.90	0.90	1.68
		Genesolv D	1.48	1.31	1.73
	445	None	2.22	1.95	1.86
		Isopropyl alcohol	2.05	1.08	1.75
	447	None	1.85	1.45	1.43
		Isopropyl alcohol	2.07	1.48	1.71
	448	None	1.83	1.02	1.57
		Genesolv D (wet)	1.44	1.05	–
	438	None	1.64	0.75	1.52
		Genesolv D (wet)	1.53	0.95	–
All-Teflon	Typical	None	4.4	0.70	2.15

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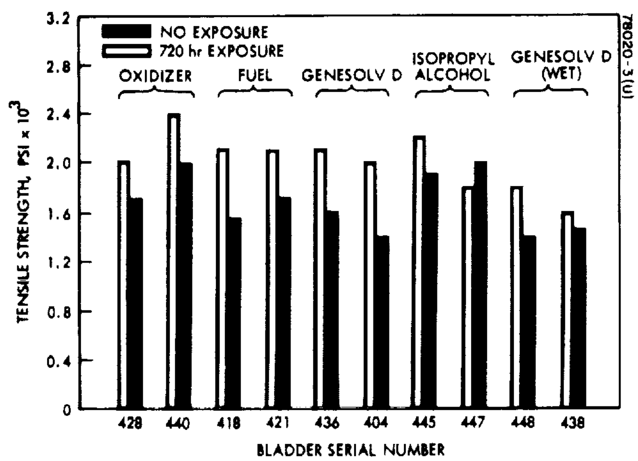

Figure 4-3. Effect of Fluid Exposure on Tensile Strength

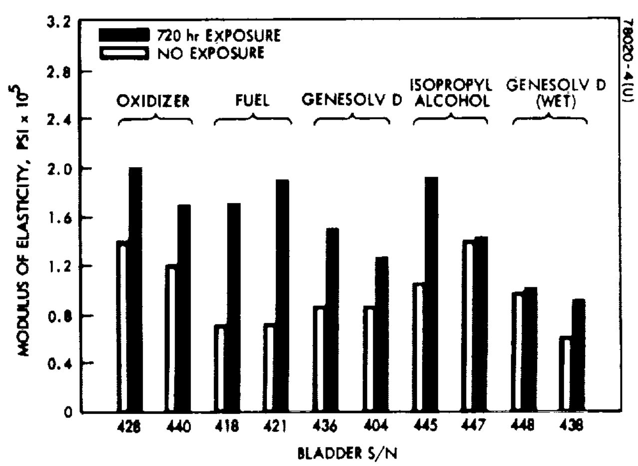

Figure 4-4. Effect of Fluid Exposure on Modulus of Elasticity

Table 4-1 also points up the poorer physical properties of the metallized material, believed due to the blisters in it, relative to the standard all-Teflon material. It is probable that the reduced expulsion life (see Section 10) of the metallized bladders is at least partially a direct result of their inferior physical properties.

One further item of interest is the marked inferiority of the Group II samples as compared to Groups I and III. Dilectrix records show that the Group II material was produced from two lots of coated foil which were not used in the construction of any other material. This points up the fact that the particular lot of foil used has a considerable bearing on the qualities of the finished product.

5. DEVELOPMENT OF AN IMPROVED INSTALLATION PROCEDURE

The metallized bladder, because of its stiffness, presents a more formidable tank installation problem than does the all-Teflon bladder. This became very apparent during the first attempt to install a metallized bladder. The bladder seems particularly susceptible to the formation of three-cornered folds and sharp creases.

To aid in bladder installation, a special insertion tool was fabricated. It is shown with a metallized bladder in Figure 5-1. The tool consists of a 3/8-inch diameter aluminum rod with a Teflon support at the tip which fits inside the bladder nipple. A plate and split ring attach to the bladder flange as shown in Figure 5-2. The plate contains a fitting that allows the bladder to be either evacuated or pressurized. The guide extension, integral with the plate, keeps the rod properly aligned and houses an O-ring that seals against the rod. Thus, when completely assembled, the insertion tool can be used to elongate the bladder by shoving the rod inward while the pressure in the bladder is simultaneously controlled.

A bladder-collapsing fixture was also fabricated (Figure 5-2). It consists of six plywood blades guided by adjustable end plates. The blades may be brought together by tension on a nylon cord through pulleys mounted on each blade. A bladder, fully collapsed between the blades, is shown in Figure 5-3.

The procedure for collapsing and inserting the bladder is as follows:

1) The bladder is assembled in the insertion tool (Figure 5-2) and placed inside the blades which are fully open.

2) A plastic cover is thrown over the collapsing fixture, and a heat gun capable of 160° F exhaust temperature is inserted under the edge of the cover. The heat gun is allowed to run about 10 minutes before the collapse is started.

3) The collapse is begun by pulling both ends of the nylon cord which runs through the blade pulleys. During the collapse, a slight positive pressure (about 1 psig) is maintained in the bladder to assure a smooth collapse around each blade. Some hand tension on the plate is necessary to keep it moving as the bladder collapses and elongates.

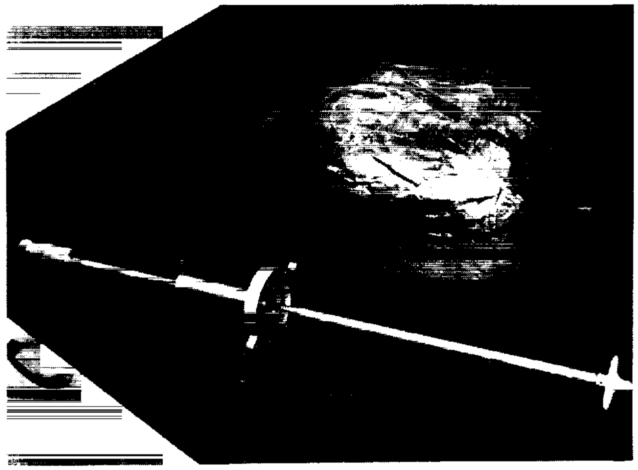

Figure 5-1. Insertion Tool
(Photo A16908)

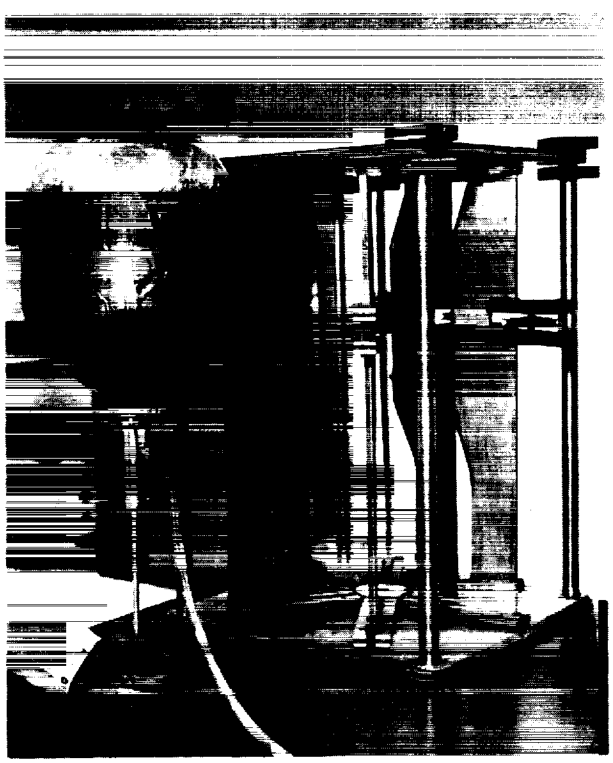

Figure 5-2. Insertion Tool and Collapse Fixture
(Photo A16916)

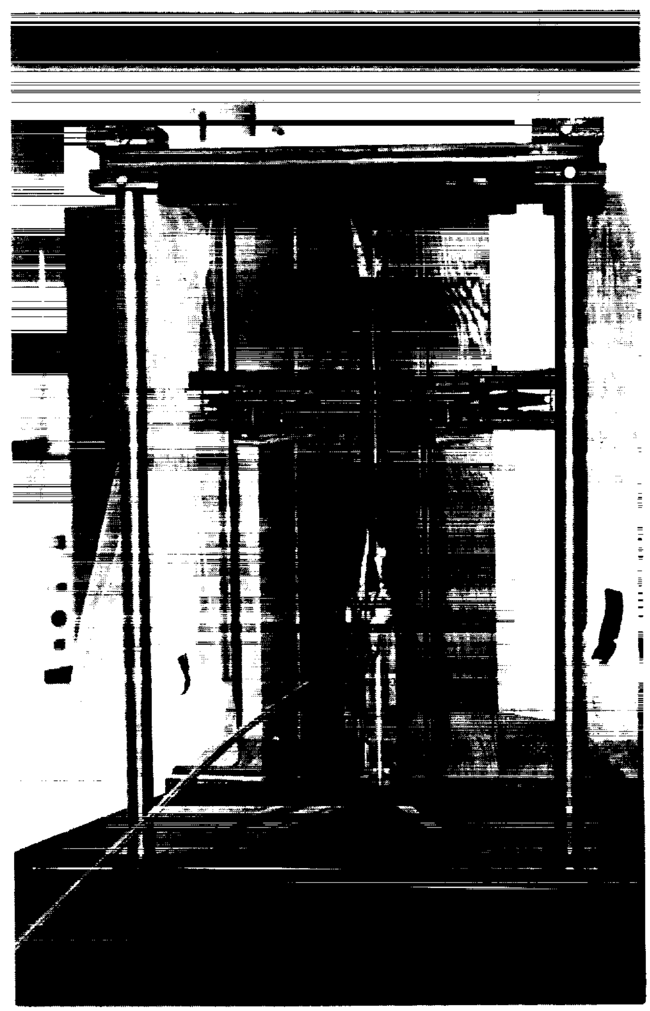

Figure 5-3. Bladder Fully Collapsed
(Photo A16917)

4) The collapse is continued until the blades meet. At this time, the bladder lobes between the blades still project too far to allow insertion. While still in the fixture, the bladder interior is evacuated, which has the effect of flattening the lobes. The vacuum is continued until the lobes are almost collapsed, but not to the point where a sharp ridge is created at the lobe tip.

5) The bladder insertion tool assembly is now removed from the fixture, and the lobes rolled slightly in one direction to form a shape slender enough to be inserted into the tank.

6) The bladder is inserted into the tank until the nipple rests in the recessed area provided for it.

7) Pressure is applied to the bladder interior, forcing it to expand slowly against the tank walls, with the guide plate following the bladder flange as it closes toward the tank mouth. Figure 5-4 shows the bladder in a transparent test tank at the start of the expansion process, and Figure 5-5 shows the bladder near the end of the expansion process.

8) As the split ring converges against the tank mouth, the collapse is halted and the split ring removed to avoid overstressing the bladder neck. The bladder neck is now hand worked into place to the point where the plate can be bolted directly to the tank flange. A pressure of about 5 psig is then applied to completely flatten the bladder against the tank walls. Some minor puckering or wrinkling of the bladder usually occurs, but this is virtually unavoidable for the relatively stiff metallized bladder.

The insertion tool and collapse fixture provides the following advantages over simple hand folding around a straight insertion rod:

1) A uniform, controlled collapse

2) Less tendency to form three-corner folds

3) Easy bladder expansion after installation in the tank

Although the collapse fixture came along too late in the program to be used for installation of the actual test bladders, installation of these bladders was successfully carried out with the insertion tool by carefully hand folding the bladder while pulling a slight vacuum on the interior. The more precise and repeatable folding that can be accomplished with the collapse fixture would be a very desirable feature for bladder production installation.

Figure 5-4. Bladder After Insertion
(Photo A16913)

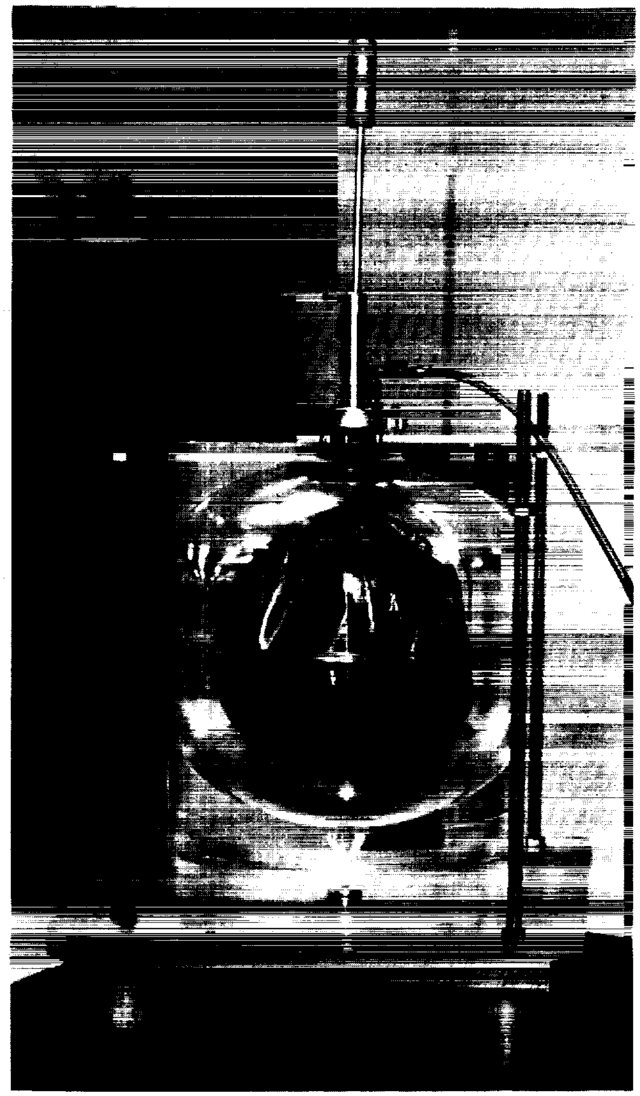

Figure 5-5. Bladder Approaching Full Expansion After Insertion
(Photo A16914)

6. PROPELLANT PERMEATION

TEST SETUP

Tests were conducted to determine the fuel and oxidizer permeation rates through samples of both all-Teflon and metallized bladder material. A schematic of the experimental apparatus is shown in Figure 6-1. The test swatch of bladder material is mounted between an outer chamber containing propellant and an inner chamber through which a gaseous nitrogen purge is maintained across the swatch surface. The nitrogen flow rate is determined by the upstream needle valve, with the back-pressure regulator assuring a minimal pressure differential across the swatch.

The gaseous purge carries all permeated propellant to the freeze trap. The quantity of oxidizer (MON-10) in the trap is determined by converting the nitrogen tetroxide to nitric acid and titrating with standardized sodium hydroxide solution. The quantity of fuel (MMH-hydrate) is determined by diluting with distilled water and titrating with standardized hydrochloric acid. All tests were conducted at 70° F.

PROPELLANT PERMEATION TEST RESULTS

The propellant permeation test results are given in Table 6-1.* For both fuel and oxidizer, the metallized material affords more than an order of magnitude decrease in permeation. Fuel permeation for metallized material is below measurable levels.

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*Oxidizer results are averages of five to six runs; fuel results are based on one run each.

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TABLE 6-1. PROPELLANT PERMEATION TEST RESULTS

Material	Permeation, $mg/in^2/hr$	
	Oxidizer	Fuel
Standard TFE-FEP (3 mils each)	5.44	0.02
Metallized bladder material	0.46	Less than 0.002

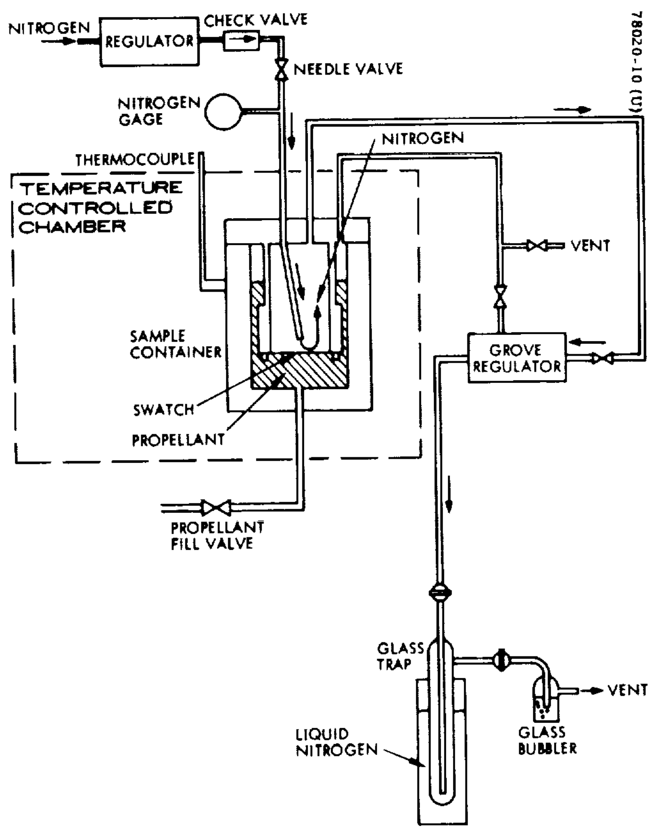

Figure 6-1. Propellant Permeation Test Setup

7. VIBRATION EFFECTS

The original test plan called for the vibration of bladders 3 and 4 at flight acceptance and type approval test levels, followed by permeation and expulsion tests. Requirements for both flight acceptance and type approval test vibration are given in Appendix B. Prior to vibration, bladder 3 was loaded with 38.1 pounds of Genesolv D referee fluid, and bladder 4 with 21.0 pounds of isopropyl alcohol referee fluid (8 percent ullage in each case). Prior to loading, a helium leak check (see Appendix C) was conducted on both bladders, resulting in near zero leakage for bladder 3 and 6 cc/hr for bladder 4. It is considered that, had sufficient time been allowed for smoothing of all bladder wrinkles, the leak rate for bladder 4 would also have been near zero (all other bladders tested had near zero leakage after installation).

Both bladders were vibrated on the same test fixture. After vibration, leak checks showed the bladder 3 leak rate to be 50 cc/hr. The bladder 4 leak rate was too high to measure with the bubbleometer since the bubble was blown out too rapidly. Both bladders were thereupon removed from the tanks and examined.

Although bladder 3 had only a modest 50 cc/hr leak rate, extensive foil tearing and delamination had occurred. Figures 7-1 and 7-2 show exterior and interior views of this bladder. A close examination of the failure areas revealed that delamination had occurred between the foil and the TFE primer layer. Figure 7-2 also shows extensive foil cracking.

The general appearance of bladder 4 was much better than that of 3, even though 4 had an extreme leak rate. Pressurization of the bladder to 1.0 psi and submersion in water revealed one of the cracks in the nipple hemisphere to be the major leak source. Figure 7-3 is an interior view, and Figure 7-4 an exterior closeup of the leak area. Several large cracks are evident in the interior photo.

No further testing was done on either bladder. It was noted by Dilectrix personnel that these bladders were constructed with dipped foil from a common lot, and they suggested that any additional vibration tests should be carried out using bladders having a different foil lot number. Therefore, bladders 3A and 4A were selected from a different foil lot and subjected to both flight acceptance and type approval test vibration. For this test series, both bladders were loaded with 38 pounds of Genesolv D since this fluid is used in the assembly level flight acceptance testing of fuel and oxidizer tanks. (Isopropyl alcohol, used in tests on bladder 4, is the referee fluid used in spacecraft systems level testing of fuel tanks only.)

In vibration testing bladders 3A and 4A, the referee fluid was removed after each axis of vibration, vacuum applied to both sides of the bladder for 1 to 2 hours, and the helium leak rate measured. Table 7-1 shows the results for both bladders. Type approval tests of all-Teflon bladders have shown no appreciable effect from vibration on any leak rate.

TABLE 7-1. BLADDER LEAK RATES DURING VIBRATION

Vibration Axis	Leak Rate, std cc/hr	
	Bladder 3A	Bladder 4A
Flight acceptance test Z	14.0	6.4
Y	13.0	11.2
X	27.7	12.9
Type approval test X	25.0	14.0
Y	45.0	42.0
Z	70.0	60.0

It is considered that the somewhat high bladder 3A leak rate at the end of flight acceptance testing resulted from a too-abbreviated purge time. In general, the results show an increasing leak rate with each axis of vibration, with the rise worsening considerably at type approval test levels.

Upon completion of vibration testing, the standpipes were removed from the tanks containing bladders 3A and 4A, and the bladders were examined internally without removing them from the tanks. Bladder 3A showed minor foil cracking and three small areas (less than 1/2 square inch) of foil breakage (pull away from the TFE layer). This bladder had numerous large puffy blisters, some 1-1/2 inches in diameter. The blisters, which occurred between the TFE layer and the foil, very likely contained Genesolv D vapor, since they retained their shape even upon probing. The appearance of bladder 4A was almost identical to 3A except that there was no evidence of foil breakage or pullaway.

Results of these vibration tests on the four bladders show that the type approval test vibration environment is too severe for metallized bladders. On three of the bladders, minor to severe foil breakage and delamination occurred. One bladder had an extreme leak rate, and the other three had rates of 50, 60, and 70 cc/hr, which approach the present specification limit of 72 cc/hr. Although three of the metallized bladders must be considered to have passed type approval vibration testing, the permeation resistance had been compromised to the point where they represented practically no improvement over all-Teflon bladders. Results of permeation tests for bladders 3A and 4A are reported in Section 8.

Figure 7-1. Bladder 3 Exterior
(Photo A17220)

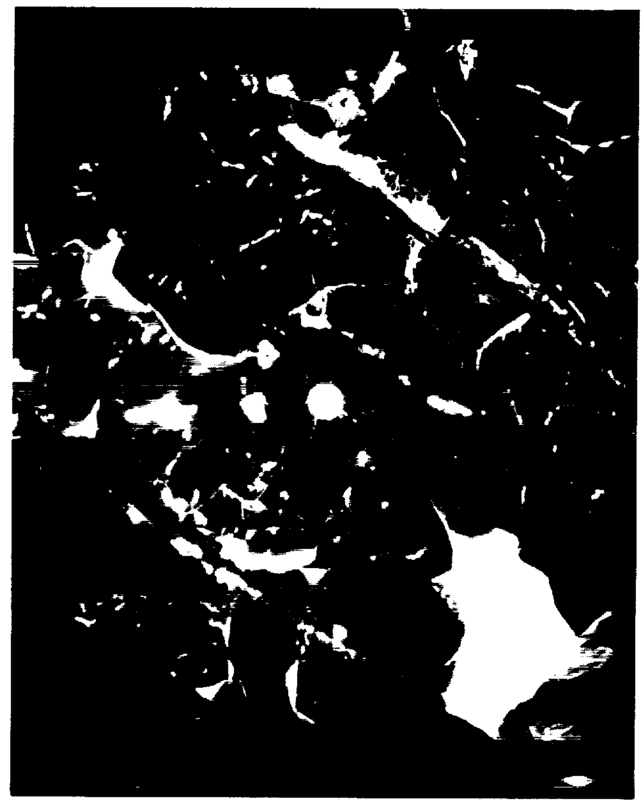

Figure 7-2. Bladder 3 Interior
(Photo A17211)

Figure 7-3. Bladder 4 Interior
(Photo A17214)

Figure 7-4. Bladder 4 Closeup
(Photo A17225)

8. GAS PERMEATION INTO PROPELLANTS

TEST SETUP AND PROCEDURE

The test apparatus used for measuring permeation of helium and nitrogen through both all-Teflon and metallized bladders is shown schematically in Figure 8-1. The tank-bladder unit was first loaded with the proper weight of propellant. The propellant weights used for the gas permeation studies were 31 ± 0.1 pounds of MON-10 oxidizer or 21 ± 0.1 pounds of MMH-hydrate fuel (leaving approximately 23 percent ullage). These correspond approximately to postmidcourse propellant weights and were used for tests at both pad pressure and operational pressure levels. Even though these weights might be somewhat lower than those ordinarily exposed to pad pressure, the resulting minor change in bladder shape is considered to have a negligible effect on permeation. The smaller weights made possible a larger ullage volume and more accurate test results.

After loading, the tank-bladder assembly was placed in a temperature-controlled chamber (Figure 8-1) and the gas side of the bladder pressurized to either 220 psig (MMH-hydrate pad pressure), 240 psig (MON-10 pad pressure), or 800 psig (postmidcourse helium system regulator lockup pressure). A temperature of 70 ± 5° F was maintained in the chamber for all tests at pad pressure levels over test periods ranging from 24 to 340 hours. For the 800-psig tests which covered a 66-hour span, temperatures were controlled to correspond approximately to those encountered in a Surveyor mission, shaded to the high side in the belief that this would constitute a worst-case condition, i.e., the higher the temperature, the higher the permeation. The following lists the temperatures and times used in the 800-psig tests:

Time, hours	Temperature (+5° F), ° F
0 – 16	85
16 – 32	70
32 – 48	60
48 – 66	50

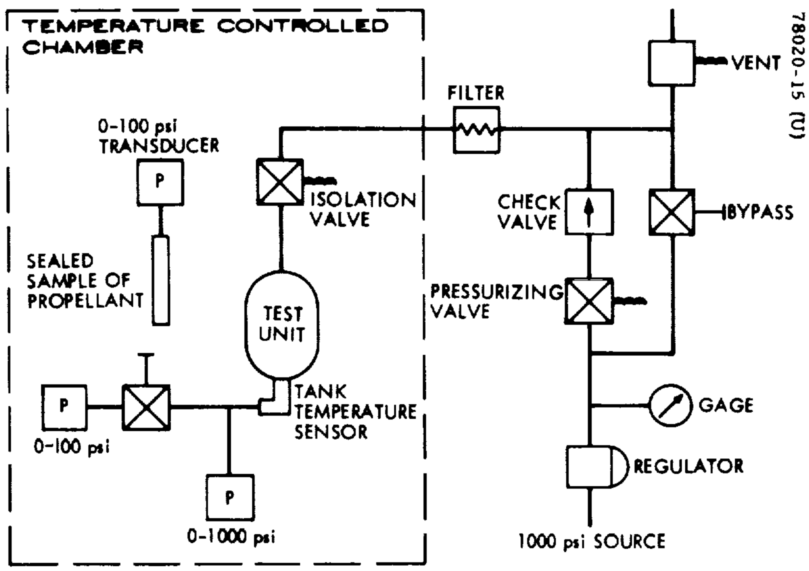

Figure 8-1. Gas Permeation Test Setup

At the end of the permeation test period, the gas side of the bladder was vented to ambient pressure and, immediately following this, the solenoid isolation valve was closed to lock up the system. The pressure on the propellant side was then recorded for approximately 1 hour until it had stabilized. Venting the gas side pressure to ambient allows the bladder to expand against the tank walls and the ullage space inside the bladder to fill with propellant vapor and gas that have come out of solution. If the ullage volume and pressure and propellant vapor pressure are known, computation of the quantity of gas in the ullage space can be made. This is added to the quantity still remaining in solution to arrive at the overall amount of gas which has permeated the bladder. The equation is as follows:

$$W_{gas} = \frac{(P - P_{prop})\, V}{RT} + P\, W_{prop}\, \alpha$$

where

W_{gas} = weight of gas permeated

P = total pressure inside bladder

P_{prop} = propellant vapor pressure

V = ullage volume

R = gas constant

T = gas temperature

W_{prop} = weight of propellant in bladder

α = solubility coefficient, gas in propellant

It is assumed that the propellant and the gas-vapor mixture in the ullage space are in thermal equilibrium within an hour after depressurization. The temperature was measured by a platinum resistance thermal sensor mounted at the base of the standpipe. The total tank pressure was measured by a 0 to 100-psi transducer mounted on the standpipe exit flow port. MON-10 vapor pressure was determined by placing a closed vial of MON-10 with an attached pressure transducer into the temperature-controlled chamber along with the test tank. Variations in the measured vapor pressure from data presented in Reference 3 that occurred during testing are believed due primarily to thermal gradients within the temperature chamber. From an analysis of test data and data in Reference 3, the following values were selected for use in the computations:

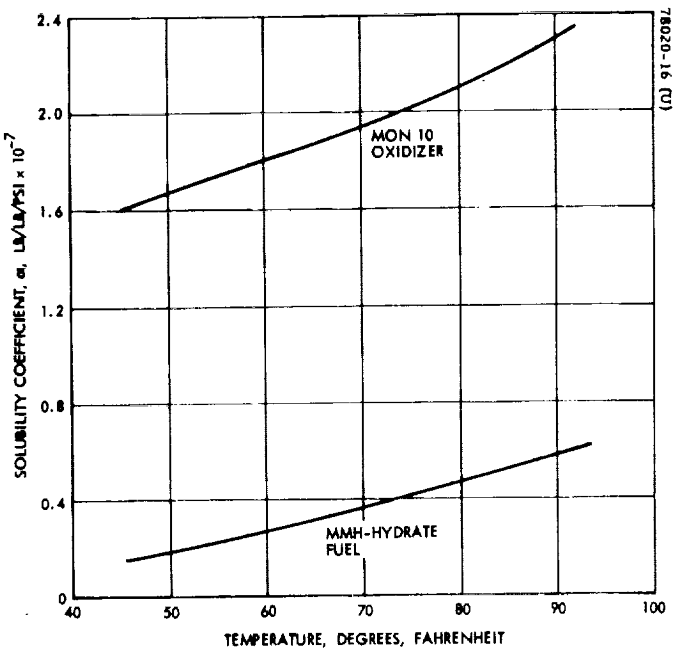

Figure 8-2. Helium Solubility in MON-10 and MMH-hydrate

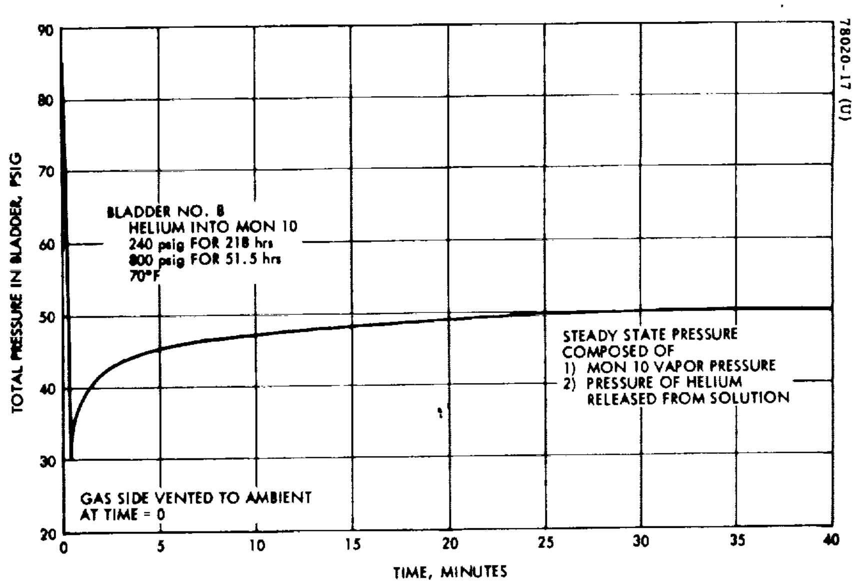

Figure 8-3. Typical Permeation Run

Temperature, °F	MON-10 Vapor Pressure, psia
50	18
70	26.5
85	39

On the basis of data obtained from Thiokol Reaction Motors Division Specification 4096 (June 1964), MMH-hydrate vapor pressures ranging from 0.4 psia at 50°F to 1.2 psia at 85°F were used.

The solubility coefficients for helium were obtained from data presented in Reference 4, and are plotted in Figure 8-2 as a function of temperature. The solubility data were obtained at two pressures: 720 and 320 psia. To simplify the calculations, the 720-psia data were used in computing the solubility coefficients, with the assumption (closely verified by the 320-psia data) that solubility is directly proportional to gas partial pressure at the temperatures of interest. Solubility data for nitrogen in the Surveyor propellants were not available. Limited data on the solubility of nitrogen in N_2O_4 and MMH are presented in Reference 5, and these were used in the calculations. The solubility coefficients at 68°F are 1.12×10^{-5} lb/lb/psi for N_2O_4 and 0.25×10^{-5} lb/lb/psi for MMH.

A typical permeation run is presented in Figure 8-3, where total pressure inside the bladder is plotted versus time. The first event observed is a rapid pressure drop as the gas side is vented to ambient pressure. As soon as the vent is complete, the solenoid isolation valve atop the tank is closed. The pressure reverses and begins to rise as gas comes out of solution in response to the diminished back pressure, and the bladder expands against the tank wall. The pressure gradually reaches a stable value as the thermal disturbance effects of gas expansion and propellant vaporization return to equilibrium. Slow release of dissolved gas near the equilibrium value may also contribute to the slow pressure rise. A sample calculation of gas permeated is presented in Appendix D.

SAMPLING PROPELLANTS DURING PERMEATION

Propellant samples were taken periodically during most of the permeation runs, and the gases thus collected were subjected to a mass spectrometer analysis at the Jet Propulsion Laboratory. Sampling tubes were approximately 100 milliliters in volume, with 25-milliliter ullage and shutoff valves at each end. Two techniques were used to take the samples. In the first technique, called the vacuum method, the sample tube was evacuated, connected to the propellant outlet on the tank, and the proper valves opened to allow the tube to fill. In the second, called the flow method, the propellant was allowed to flow continuously through the sample tube, with a small quantity exhausted overboard. The sample tube exit valve was cracked only slightly in an attempt to limit the pressure drop of the propellant as it flowed through the tube and thus minimize loss of dissolved gases. In either method, the ullage space was afterwards emptied, evacuated, and opened to the main chamber.

Since the man-rated pressure for the propellant tanks is 365 psig, it was necessary in the 800-psig tests to vent to this pressure prior to sample taking. These samples therefore show meaningful results only when the concentration level is lower than that corresponding to saturation at 365 psig.

In analyzing a sample, the propellant is first frozen out and the percentage of helium, nitrogen, etc., in the remaining gases determined by use of a mass spectrometer. A description of the analysis technique is given in Appendix E.

TEST RESULTS AND DISCUSSION

Tests Using Oxidizer

Permeation test results for helium and nitrogen into MON-10 oxidizer are shown in Figure 8-4. The permeation levels are given in standard cubic centimeters of the permeating gas per gram of oxidizer in the bladder. This parameter was selected as being more appropriate than percent saturation for comparing two gases, since it is the volume of gas in solution and not the saturation level per se which can affect vernier engine response. Fully saturated values have been indicated on the plot ordinate. The results for each bladder tested will be discussed in turn. Table 8-1 is a summary of the permeation data.

Bladder 5 was the first to undergo permeation testing. It had not been subjected to either propellant storage or vibration prior to testing. The first test ran for 336 hours at a helium pressure of 240 psig, and the results are indicated by the connected points. During this test, the gas side of the bladder was vented to ambient pressure once a day and a permeation reading taken as described in the preceding discussion of "Test Setup and Procedure." Each depressurization allowed some gas to come out of solution, and a gas bubble formed above the propellant. It was assumed that this gas bubble would rapidly dissolve once pressure was reapplied. Test results indicate that this assumption was erroneous, at least for the latter part of the test when the bubble contained a considerable quantity of gas. The helium level continued to rise even after saturation had been reached. This indicates that the bubble failed to dissolve, and that helium continued to permeate the bladder even though the total helium in the bladder exceeded the amount required to saturate the oxidizer. Another effect of multiple depressurizations is that the helium concentration in the propellant is lowered each time a depressurization occurs, thereby artificially raising the average concentration gradient across the bladder and causing an increase in permeation over that which would occur with constant applied pressure.

The above considerations must be kept in mind when interpreting the results for this particular test. It is considered that these effects were small during the initial phase of the test (up to 120 hours), but that beyond this point they became increasingly significant, as is indicated by the somewhat increased slope of the curve. The total time to saturate of 240 hours must be considered overly conservative.

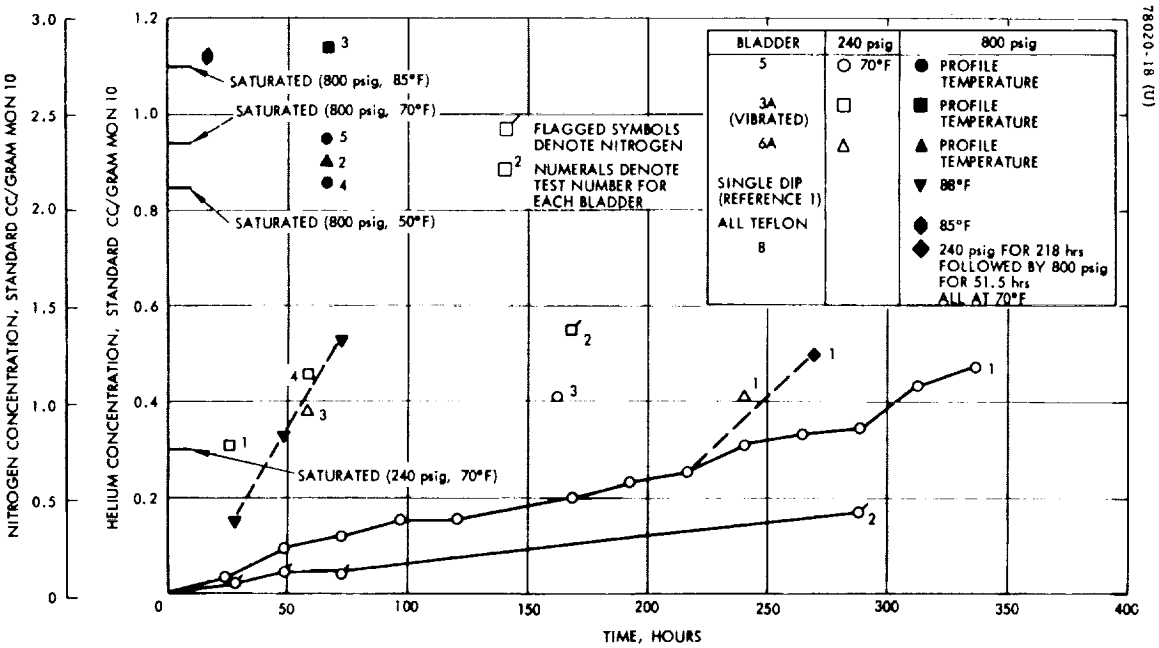

Figure 8-4. Permeation of Helium and Nitrogen Into MON-10

TABLE 8-1. DATA SUMMARY OF HELIUM AND NITROGEN PERMEATION INTO MON-10

Bladder	Test No.	Gas and Pressure, psig	Time at Pressure, hours	Temperature, °F	Total Pressure, psig	MON-10 Vapor Pressure, psig	Net Gas Pressure, psi	Weight of Gas Permeated, pound	Concentration, std cc/gram	Percent Saturated at Test Pressure
5	1	Helium, 240	24	70	15.3	13.0	2.3	0.00015	0.03	10
			48		20.0		7.0	0.00046	0.09	30
			72		22.0		9.0	0.00059	0.12	40
			96		24.8		11.8	0.00078	0.16	53
			120		24.8		11.8	0.00078	0.16	53
			168		28.0		15.0	0.0010	0.20	67
			192		30.5		17.5	0.0012	0.23	77
			216		31.5		18.5	0.0013	0.26	87
			240		36.3		23.3	0.0015	0.31	103
			264		38.0		25.0	0.0016	0.33	110
			288		39.0		26.0	0.0017	0.35	117
			312		45.8		32.8	0.0022	0.44	147
			336		49.0		36.0	0.0024	0.48	160
	2	Nitrogen, 240	28	70	14.3	13.0	1.3	0.0010	0.028	1.1
			48		18.0		5.0	0.0038	0.11	4.4
			72		17.5		4.5	0.0035	0.10	4.0
			288		31.7		18.7	0.014	0.41	16.4
	3	Helium, 240	162	70	44.0	13.0	31.0	0.00206	0.41	137
	4	Helium, 800	66	Profile	73.0	4.5	68.5	0.0043	0.86	101
	5	Helium, 800	66	Profile	80.5	4.5	76.0	0.0048	0.95	112
6A	1	Helium, 240	260	70	44.0	13.0	31.0	0.00206	0.41	137
	2	Helium, 800	66	Profile	76.0	4.5	71.5	0.0045	0.90	106
	3	Helium, 240	58	70	42.0	13.0	29.0	0.00192	0.38	127
8	1	Helium, 240 and 800	218 hr at 240, 50 hr at 800	70	50.5	13.0	37.5	0.0025	0.50	53
3A (vibrated)	1	Helium, 240	24	70	36.0	13.0	23.0	0.0015	0.31	103
	2	Nitrogen, 240	168	70	76.0	13.0	63.0	0.048	1.38	55
	3	Helium, 800	66	Profile	95.0	4.5	90.5	0.0057	1.14	135
	4	Helium, 240	58	70	26.0*	13.0	13.0	0.0023	0.46	153
All-Teflon	1	Helium, 800	16	85	110.5	25.5	86.0	0.0056	1.12	102

*See text for discussion of bladder 3A. The propellant weight for this run is 21.7 pounds, and the ullage volume is 340 in^3.

The second test conducted on bladder 5 ran for 290 hours with nitrogen at 240 psig as the pressurant gas. This test began before the effects of depressurization in the first test were understood. Thus, three depressurizations were made and permeation readings taken early in this test in the same manner as the first test. After the first three points, the error due to bubble accumulation was recognized, and no further depressurizations were carried out until test termination.

The nitrogen test showed 0.41 std cc/gram concentration level after 290 hours.* Even though this represents only 16 percent saturation, the volume of gas is greater than if the oxidizer is fully saturated with helium at the same pressure. Thus, there appears to be no advantage, and possibly a disadvantage, in the substitution of nitrogen for helium as the pad pressurant gas.

The third test with bladder 5 used helium at 240 psig as the pressurant gas. Constant pressure was maintained until the end of the 162-hour test period, at which time a depressurization and equilibrium measurement was carried out. The results indicated a 0.41 std cc/gram gas concentration, which is 37 percent above the indicated full saturation level. The discrepancy could be due to entrainment of gases other than helium (e.g., nitrogen) in the propellant prior to or during the loading operation. Another possibility is that the MON-10 vapor pressure values used are actually too low. Some investigators have reported values about 50 percent greater than those used herein (Reference 6). It is noted in this regard that three saturation data points for other bladders lie at about the 0.4 std cc/gram level, indicating at least that the test data herein are consistent. In any case, it is a reasonable conclusion that saturation occurred during the 162-hour period. This result is contrasted with that of the first test of bladder 5, which showed only about 0.2 std cc/gram concentration after 162 hours. The poor results in the third test are undoubtedly due to bladder deterioration caused by both the multiple depressurizations of the first two tests, and by the long exposure to oxidizer, which, by the end of the third test, amounted to about 800 hours.

Although bladder 5 no longer represented a new bladder, two permeation tests using helium at 800 psig were carried out for 66-hour periods (tests 4 and 5). Mission profile temperatures were simulated for these tests, as described in the preceding discussion of "Test Setup and Procedures." The final oxidizer temperature was 50° F, and both data points indicate slightly over full saturation at this temperature. The same comments apply for test 3 in regard to the disagreement with theoretical saturation values, although the disagreement is much reduced for tests 4 and 5.

At the end of the bladder 5 permeation tests, a leak check of this bladder was made by applying 4-psig helium pressure to the inside of the bladder with a bubbleometer attached to the gas side. The leak rate was 120

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*This result agrees with the nitrogen concentration level presented in Figure 14 of Reference 1. However, the bladders referred to in Reference 1 used a 1/2-mil, single-dip foil layer and had been subjected to vibration.

std cc/hr, which is nearly twice the acceptable leak rate for an all-Teflon bladder and is an indication of the severe effects of long-term oxidizer storage combined with the flexing of the top of the bladder during approximately 21 pressurization cycles.

To compare with the results of the metallized bladders, an all-Teflon bladder was tested over a 16-hour period at 85° F and 800-psig applied helium pressure. As indicated in Figure 8-4 the all-Teflon bladder allowed full saturation of the oxidizer within this time period. This agrees with the results of the previous all-Teflon bladder tests (Appendix A).

Bladder 6A was the second to be tested. It was originally scheduled to replace bladder 6 in the expulsion test series, but was first diverted to permeation testing in an attempt to verify the results of bladder 5. Prior to the beginning of permeation testing, this bladder had been subjected to oxidizer storage for 200 hours. The first test of bladder 6A used helium at 240 psig as the pressurant gas over a 240-hour period. As in the last three tests of bladder 5, depressurization and data taking were done only at the end of the test period. The 240-hour test period was chosen because it was approximately the saturation time indicated in the first test of bladder 5. The test point for bladder 6A showed 0.41 std cc/gram, about 37 percent over full saturation.

The second test of bladder 6A used helium at 800 psig as the pressurant gas. Mission profile temperatures were simulated, and the oxidizer was fully saturated after 66 hours.

A third test of bladder 6A was performed over a 58-hour period using helium at 240 psig. The gas concentration was 0.38 std cc/gram, about 27 percent over full saturation. (The same comments as before apply to the discrepancy between this result and the indicated saturation level.) By the end of the test, this bladder had been exposed to oxidizer for 564 hours and had been subjected to three loading operations. This exposure is somewhat greater than would ordinarily be encountered aboard a spacecraft, where exposure should not exceed 360 hours. However, the number of loading and pressurization cycles do not exceed those normally encountered, since these operations are done at least twice during flight acceptance tests of tank and spacecraft, although with referee fluid instead of oxidizer.

The bladder 6A test results tend, in general, to confirm those for 5, with the possible exception of the third test with 6A, which indicated full saturation had occurred after only 58 hours at 240 psig. In contrast, the first test of bladder 5 at 240 psig showed only 0.12 std cc/gram at the 72-hour mark, or about 33 percent saturated. At this point in the test, 5A had undergone three pressurize-vent cycles, as had 6A after its third test. The major difference is the oxidizer exposure time, which for bladder 5 was 72 hours and for 6A was 564 hours.

Although bladders 5 and 6A were manufactured using identical techniques, the dipped foil came from different lots, and the appearance of the finished material was not identical. The foil in bladder 6A had a deeper gold color than the foil in 5. It was noted during installation of 6A that it had more of the larger diameter (approximately 1 inch) blisters on the interior than any other bladder tested. After the permeation tests on 6A, three expulsion tests were conducted as described in Section 10. Examination of the bladder after the expulsions revealed that virtually 100 percent delamination of the outer FEP layer had occurred. The separation took place between the bare foil and the TFE primer layer, with the primer layer sticking to the outer FEP layer. The FEP layer itself remained largely intact and, in essence, comprised a sheath around the entire bladder. Whether the delamination took place prior to, during, or after the permeation tests is not known. In any case, it is doubtful whether delamination of this layer would of itself result in increased permeation provided the foil layer remained intact. Bladder 5, which was put through one expulsion test, showed none of the delamination effects noticed for 6A, although there were a few minor breaks in the FEP layer. Section 10 contains a more complete discussion of the post-test condition of these bladders.

Because bladder 5 underwent multiple pressure-vent cycles in its first test, and bladder 6A underwent a 200-hour prepermeation oxidizer storage, it was decided to test a third bladder, No. 8, which would be loaded and placed immediately in test in an attempt to determine "best case" performance. This test was performed using helium at 240 psig for 218 hours to simulate a prelaunch period, followed by 51 hours at 800 psig to simulate the mission. The tank temperature was maintained at 70°F throughout this test, since it approximated the mission average.

As shown in Figure 8-4, the resulting helium concentration was 0.5 cc/gram at the conclusion of the test, corresponding to 53 percent saturation. If the concentration level at the end of the 218-hour period is taken the same as for bladder 5, the dashed line extending from the 218-hour mark to the test point for bladder 8 represents the average concentration rise rate during the 51-hour period at 800 psig, or 0.0045 cc/gram/hr. This value is about 3.3 times the rise rate indicated for bladder 5 at 240 psig at a comparable saturation level, which is very close to the ratio of the applied pressures in the two cases. Thus, the data for the first test of bladder 5 would appear to correlate with the results for bladder 8.

Shown in Figure 8-4 for comparison are data from the test described in Appendix A for a metallized bladder constructed of single-dip instead of double-dip aluminum foil. The applied pressure was 800 psig, and the average temperature was 90°F. Six pressure-vent cycles were performed during the 72-hour test, and the data are open to some question for the same reasons as in the first test of bladder 5. Data for 24, 48, and 72 hours are shown on the plot. The concentration rise rate shown is about 50 percent higher than that indicated by the dashed line for bladder 8. Some of this increase may be due to the higher temperature. In any case, the above data would indicate that bladders used in the present study are at least equal to those of Appendix A with respect to permeation resistance.

The remaining bladder subjected to permeation tests was bladder 3A. This bladder had been subjected to flight acceptance and type approval test vibration levels prior to permeation testing. Bladder 3A was substituted for bladder 3 after vibration of 3 caused such extensive damage that it was decided to discontinue further tests with it (see Section 7).

Bladder 3A leak rate at the end of vibration testing was 70 cc/hr. An examination of the bladder interior while still in the tank showed approximately 20 large blisters up to 1-1/2 inches in diameter, but evidence of only minor foil damage (three areas of about 1/2 by 1/4 inch where the foil had pulled away from the TFE layer). It was therefore decided to continue with permeation testing of this bladder, although it was anticipated that it would show poor results.

The permeation results for 3A are shown in Figure 8-4. The first test used helium at 240 psig and showed that saturation occurred within 24 hours. The second test used nitrogen at 240 psig. The concentration level was 1.38 cc/gram after a 168-hour period, the highest gas concentration level reached in the permeation test series.* A third test was made with helium at 800 psig and mission profile temperatures for a 66-hour period, with a resulting concentration level of 1.14 cc/gram. This value is approximately 35 percent in excess of the indicated saturation level for 50°F. The reason for the high value is not understood, but it is similar to discrepancies noted in the tests at 240 psig for bladders 5 and 6A. Gas entrainment during loading could not completely account for the 34 percent excess. As mentioned previously, the full saturation values indicated may be low.

A fourth test was conducted using helium at 240 psig for a 58-hour period to compare with the 58-hour test of bladder 6A. During the sample-taking procedure at the end of this test, a large quantity of MON-10 was accidentally lost. By postweighing the tank, a revised propellant weight was obtained, and the calculations made assuming that the propellant weight of 21.7 pounds contributed all the gas measured. The resulting concentration level was 0.46 cc/gram, which exceeds full saturation by about 50 percent. This particular result is open to some question because of the MON-10 loss, but there would appear to be little doubt that the oxidizer was saturated.

Tests Using Fuel

Since the solubility of helium in MMH-hydrate is about one-fifth of its solubility in MON-10, the effects of dissolved gas in the fuel are of much less importance. Because of this, only limited permeation tests were conducted with fuel.

Bladder 4A was used in the first fuel test. This bladder had been substituted for bladder 4 after the latter had emerged from flight acceptance and type approval test vibration with a leak rate too high to measure with the bubbleometer. Bladder 4A was also subjected to flight acceptance and type approval test vibration, after which its leak rate was 60 cc/hr. Interior

*This is three times the highest concentration level reported in Reference 1.

blisters very similar to those described for bladder 3A were discovered upon internal examination (see Section 7). However, there appeared to be no foil breakage or delamination.

The first permeation test for bladder 4A was performed with helium at 240 psig. The temperature was maintained at 70°F. After 312 hours, the helium pressure was vented, and the measured equilibrium pressure was 16.4 psia. Since MMH-hydrate is pressurized with nitrogen for loading, it was assumed to be saturated with nitrogen at one atmosphere before testing began. Hence, the above reading represents the total pressure due to helium, nitrogen, and fuel vapor pressure. The vapor pressure of MMH-hydrate at 70°F is 0.8 psi, leaving 15.6 psia due to the two gases. When the gas side of the bladder is vented to atmosphere, helium evolving from the fuel expands the bladder against the tank wall. This should allow most of the nitrogen to come out of solution in order to maintain equilibrium between the nitrogen in the fuel and that in the space above it. Thus, it has been assumed in all calculations for fuel that a quantity of nitrogen equal to the amount required to saturate at one atmosphere (237 std cc) is present in the ullage space.

When the calculations were carried through on this basis, a helium concentration about five times the full saturation value resulted. JPL analysis of a fuel sample at the end of this test showed that the gas in the fuel was 13 percent methane, indicating that fuel decomposition had taken place. Cause of the decomposition is not known. The test results must be considered invalid, since the gas composition in the ullage space cannot be determined, and the assumed fuel vapor pressure may be in error.

Upon attempting to reload bladder 4A for a second test, the bladder was discovered to be leaking badly. It was removed from the tank and examined. Viewing the interior against a lighted background (Figure 8-5) revealed extensive cracking and tearing of the foil. Pressurization of the bladder to 1.0 psig and submersion in water revealed that one of the cracks was leaking severely. There appeared to be only a few small (1/2 square inch or so) areas where foil delamination had occurred. It was concluded that nearly all damage had occurred during vibration and that one of the weakened areas had separated during either the vent operation at the end of permeation testing or during subsequent purging of the bladder prior to reloading. The bladder was not tested further.

To complete the required tests with fuel, a new bladder, 4B, was selected. In order to meet schedule requirements, this bladder was placed immediately in permeation testing without prior vibration. The first test used nitrogen at a pressure of 220 psig for 7 days. After this period, the fuel was found to contain 0.245 cc/gram, corresponding to 63 percent saturation at 220 psig. A JPL sample taken after 5 days showed 0.21 cc/gram, a result in line with the final 0.245 cc/gram.

The second test of bladder 4B used helium at 800 psig. Mission profile temperatures were simulated over a 66-hour period. The net helium partial pressure was 12.7 psi, which gives a concentration of 0.22 cc/gram, or 30 percent over saturation. The high value obtained would indicate that

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Figure 8-5. Bladder 4A Interior
(Photo A17218)

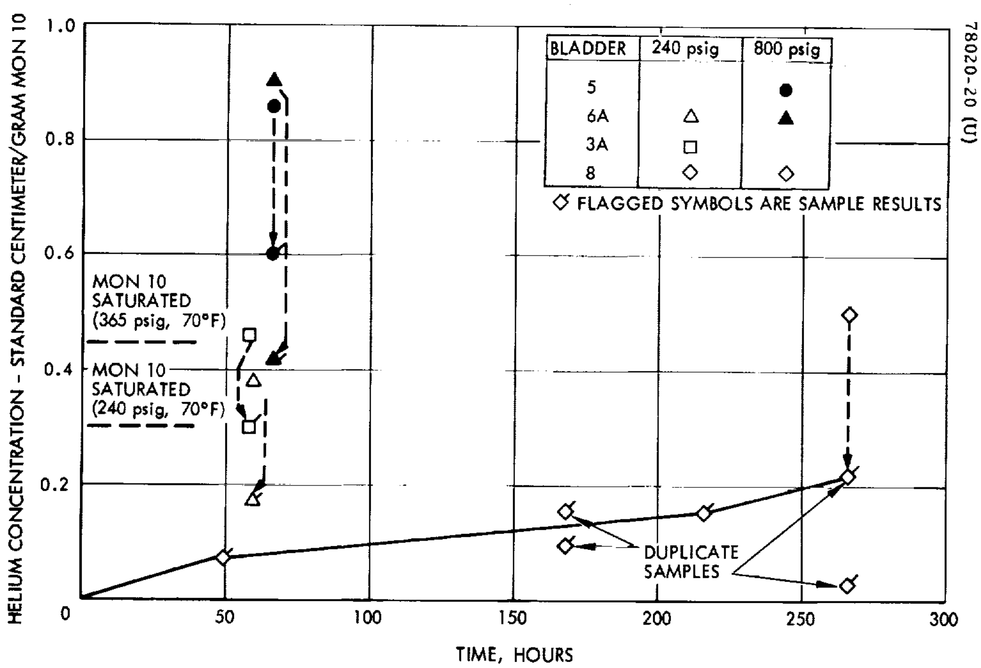

Figure 8-6. Comparison of Sample Analysis
With Partial Pressure Method

the quantity of residual nitrogen may be greater than assumed. A sample analyzed by JPL at the conclusion of the test showed 0.17 cc/gram helium concentration, which corresponds to 100 percent saturation. There would appear to be little doubt that the fuel was fully saturated. This result is not surprising, even with an unvibrated bladder, in view of the small quantity of gas required to accomplish saturation.

Results of Propellant Sample Analyses

As previously discussed, samples of propellants were taken at intervals during most of the permeation tests and subjected to mass spectrometer analysis at JPL. Examination of the results shows that virtually all samples taken by the vacuum method gave helium or nitrogen concentration levels ranging from 10 to 50 percent of the levels obtained by the equilibrium pressure method. The low readings could have resulted from either of the following causes:

1) The propellant admitted to the sample tube may have contained a smaller quantity of gas by virtue of the fact that a significant fraction of the sample was located outside the main tank in connecting lines and fittings, a region poorly accessible to the permeating gas.

2) Gas leakage from the sample tube may have occurred between the time the sample was taken and the subsequent analysis. Since the sample tubes had been leak checked, this should have occurred only infrequently, perhaps as a result of foreign particles on the valve seat, etc.

In view of the poor agreement between the pressure measurement data and the sample analyses, the technique used for taking samples was changed to the flow method described earlier. The results using the flow method show improved, though still disappointing, agreement. Figure 8-6 compares the results of all sample analyses taken by the flow method with the corresponding pressure measurement results (two samples taken by the flow method are not shown in this figure because the values were obviously not valid). Samples from the three 800-psig tests should show saturation at 365 psig, since the pressure was lowered to this value prior to taking samples. The samples from bladders 5 and 6A show approximately correct values. The sample from bladder 8 is 50 percent low.

Conclusion

Except for the early phases of the first test of bladder 5 and the one test of bladder 8, all tests with helium as the pressurant gas resulted in saturated propellant. That saturation occurred rapidly for vibrated bladders is perhaps not too surprising. However, the fact that the permeation resistance of bladder 5 apparently deteriorated rapidly during testing, and that bladder 6A saturated in 240 hours or less in its first test, having been subjected only to 200 hours of oxidizer storage prior to test, indicates that even unvibrated bladders are extremely sensitive to moderate amounts of flexing or propellant exposure. Only bladder 8, tested without prior propellant exposure and subjected to only one propellant loading operation, gave reasonably satisfactory results. The only reasonable conclusion from these tests is that the present metallized bladders will offer very little, if any, improvement over all-Teflon bladders under use conditions presently encountered in the Surveyor program.

9. EFFECTS OF PERMEATION ON SPACECRAFT STABILITY

During the spacecraft terminal descent, the time from retro case ejection to segment control (minimum acceleration phase) is a period of continuous low thrust operation of the vernier engines, i. e., the acceleration control loop commands minimum acceleration, driving each engine to a low average steady-state thrust of about 38 pounds. During low thrust operation, the pressure drop through the engine throttle valves is greatest. If the propellants are partially or fully saturated with helium, gas will come out of solution between the throttle valve and the thrust chamber. The two-phase flow that occurs under these circumstances decreases engine dynamic response.

An analysis of the transient response of the vernier engines with saturated propellants, similar to that of Reference 4, results in the following transfer function relating the actual thrust to commanded thrust:

$$\frac{\Delta F}{\Delta F_c} = \frac{\beta \tau S + 1}{(\tau S + 1)\left[\left(\frac{S}{\omega_n}\right)^2 + \frac{2\zeta}{\omega_n} S + 1\right]}$$

where

ΔF = change in thrust

ΔF_c = change in commanded thrust

β = constant (function of oxidizer/fuel ratio, chamber pressure, and injector pressure drop)

τ = time constant

S = La Place operator

ω_n = throttle valve natural frequency

ζ = damping ratio

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Values of β, ω_n, and ζ were determined from actual firing tests of the vernier engines and water flow tests of the throttle valve.

To permit stability margin calculations for varying saturation levels, the following parametric values were selected based on actual firings of vernier engines with both saturated and gas-free propellants.

$$\tau = 0.155\, X + 0.004$$

$$\beta = 0.21$$

$$\omega_n = 264 \text{ rad/sec}$$

$$\zeta = 0.4$$

where X = saturation fraction $0 \leq X \leq 1$

The stability calculations using these parameters were made by B. N. Smith and S. M. Levy of the Guidance and Controls Department. The open-loop transfer function of the inner rate (vernier propulsion system) loop is:

$$\text{OLTF} = \left[\frac{23.9\left(\frac{S}{2}+1\right)(S+1)}{\left(\frac{S}{60}+1\right)\left(\frac{S}{30}+1\right)(S+0.05)}\right]\left[\frac{(0.21\tau S+1)}{(\tau S+1)}\right]\left[\frac{1}{\left(\frac{S}{264}\right)^2+\frac{0.85}{264}+\frac{1}{264}}\right]$$

Gain and phase margin were computed for values of x of 0, 0.25, 0.5, 0.65, 0.8, and 1.0. The results are shown in Figure 9-1.

It is apparent from Figure 9-1 that a large reduction in saturation fraction is needed to cause a significant increase in gain margin. In fact, the gain margin does not improve until the saturation level drops below 30 percent. The phase margin curve, while indicating a continuing increase as the saturation level drops, shows that the improvement is not marked until the saturation fraction diminishes below about 50 percent. The phase margin increases from 9 to 16 degrees as the saturation fraction drops from 100 to 50 percent, but is 30 degrees at 0 percent saturation.

The lowest saturation level achieved in the permeation tests for combined 9-day prelaunch and mission simulation was 53 percent in bladder 8. This was achieved under ideal conditions (no vibration or prior referee propellant exposure and minimum prelaunch period). It would thus appear that no improvement in gain margin, and only a modest phase margin improvement, would occur as a result of using the metallized bladder under the most ideal conditions. Under the necessarily more severe environment (vibration and referee propellant loading) of propellant tank and spacecraft flight acceptance tests, the improvement would be small and perhaps negligible, especially if the bladder experiences more than the minimum propellant storage time.

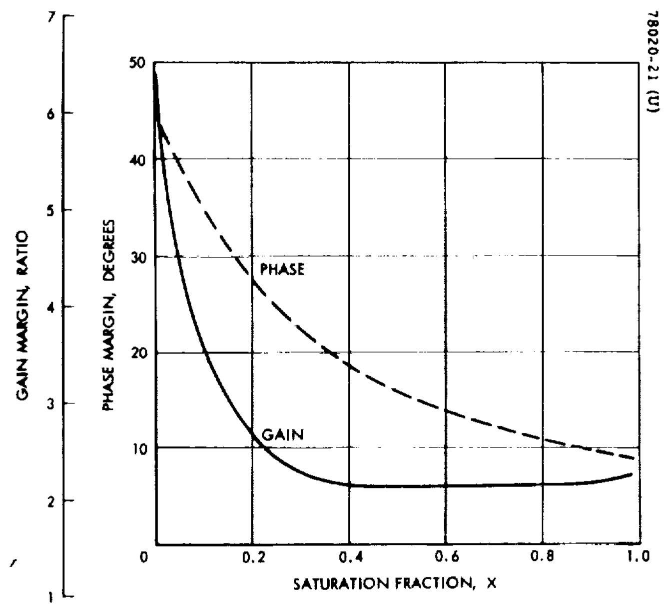

Figure 9-1. Variation of Gain and Phase Margin With Saturation Fraction

10. PROPELLANT EXPOSURE AND EXPULSION TESTS

TEST SETUP AND PROCEDURE

The test apparatus for propellant expulsion tests is shown schematically in Figure 10-1. The propellant weights used in the storage and expulsion tests were 35 ± 0.1 pounds of MON-10 and 24 ± 0.1 pounds of MMH-hydrate. After loading, the test unit was placed in a temperature-controlled chamber. For all storage tests, a temperature of 70 ± 10°F was maintained along with a helium pad pressure of 40 psig for oxidizer and 20 psig for fuel. For expulsion tests, the tank could be oriented either flange up or flange down and the temperature controlled to the desired value. Helium was supplied through a regulator at about 745 psi. The expelled fluid was caught and weighed in a closed-catch tank.

The following measurements were taken during expulsions:

1) Pressurant pressure just upstream of entry port
2) Propellant pressure just downstream of exit port
3) Catch tank weight
4) Propellant temperature (base of the standpipe)
5) Differential pressure (pressurant inlet minus propellant exit) was measured by zero-shifting the propellant pressure transducer output so that it read the same as the pressurant pressure just prior to each run, and then recording the differential signal from the two separate transducers.

The following procedure was followed for all expulsions:

1) The unit was placed in the temperature conditioning chamber, the necessary lines connected, and temperature conditioning begun. The temperature sensor located on the standpipe was monitored during the conditioning. After the sensor indicated the desired temperature had been reached, this condition was maintained for 3 hours to assure temperature equilibrium.

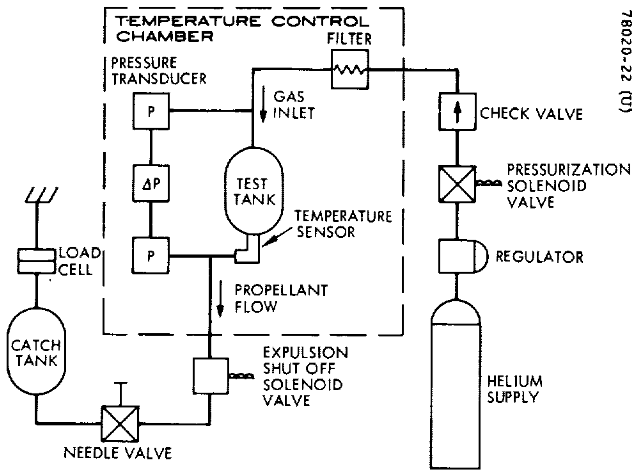

Figure 10-1. Expulsion Test Apparatus

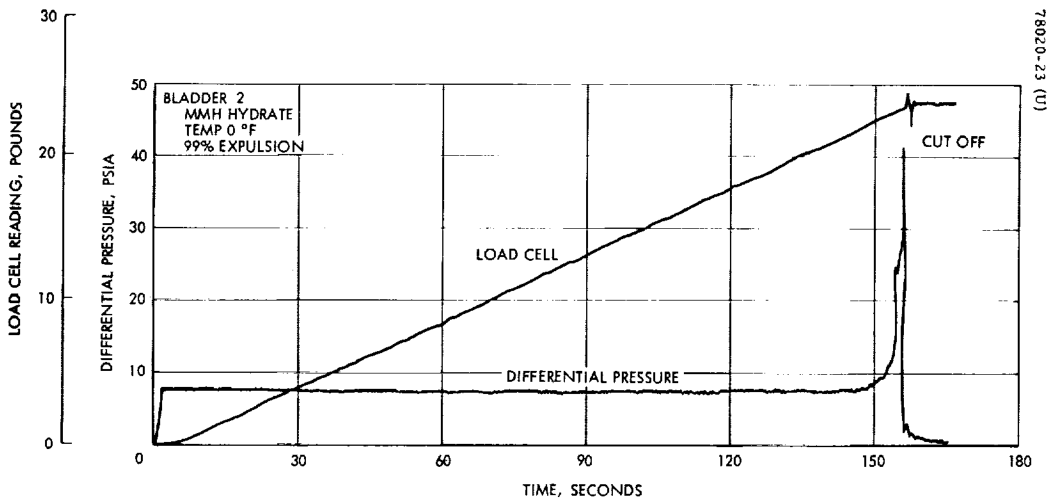

Figure 10-2. Typical Expulsion Plot

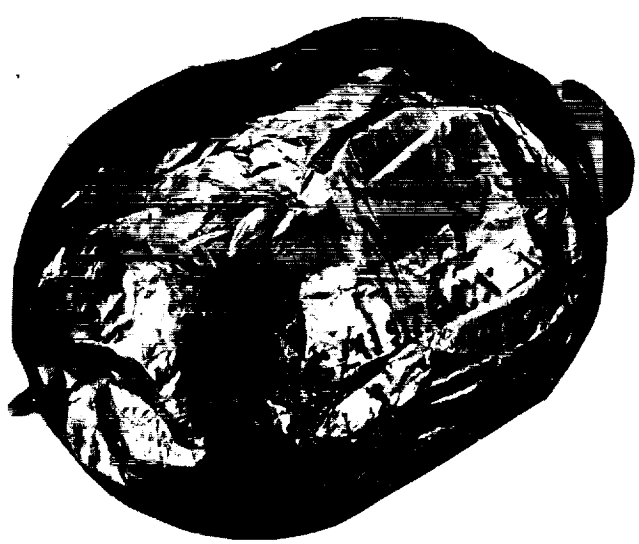

Figure 10-3. Tear in Bladder 4B
(Photo A17224)

2) The pressurant pressure was set at 745 psig.

3) The expulsion cycle was started by opening the expulsion shutoff valve. Catch tank weight was monitored visually, so that for flange up runs the expulsion could be terminated after 90 percent had been expelled. Figure 10-2 presents pressure drop and catch tank weight of a typical expulsion.

4) The temperature conditioning chamber was opened, and the unit was allowed to approach ambient temperature before reloading for the next expulsion.

TEST PROGRAM

Type approval testing calls for subjecting the bladder to four expulsion cycles in accordance with Table 10-1. The flange up runs are, in effect, -1 g expulsions and are manually terminated after the catch tank indicates 90 percent has been expelled. After the two 0°F expulsions, the bladder is allowed to warm to 50°F, then purged with dry nitrogen, evacuated on both sides, and leak checked.

Table 10-2 lists the bladders subjected to exposure and/or expulsion tests, together with their prior test histories.

TEST RESULTS AND DISCUSSION

Table 10-3 lists the important test parameters and results for all bladders tested during this program. Each bladder will be discussed in turn.

Bladder 1

Bladder 1 developed an extreme leak rate after the third expulsion (0°F, 90 percent). Examination of the bladder showed a circumferential tear at the location of the standpipe O-ring, comprising about half the total circumference. This tear was totally within the Teflon portion of the bladder. It cannot be definitely established whether this tear was a result of the long-term storage in Genesolv D or whether it is related to a generic problem in the construction of this particular bladder. No other failures of this type of either all-Teflon or metallized bladders have occurred. An examination of the bladder's interior showed only mild foil cracking, and no puffy blisters were visible. External appearance could be generally described as good, the only irregularities being several small (less than 1/4 by 1/4 inch) blisters.

Bladder 2

The entire expulsion series of four tests was completed on bladder 2. After the fourth expulsion, an extreme leak rate was evident. Examination of the bladder showed that a 1-inch long tear had occurred near the bladder nipple, in a part of the bladder which collapses around the standpipe support. Figure 10-3 shows an identical failure that occurred in bladder 4B (also a fuel bladder). In spite of this failure, which undoubtedly occurred at the conclusion of the

TABLE 10-1. TYPE APPROVAL TEST EXPULSION SERIES

Expulsion	Tank Orientation	Temperature, °F	Percent Expelled	Flow Rate
1	Flange up	70 ± 5	90	Maximum thrust
2	Flange up	100 ± 5	90	Maximum thrust
3	Flange up	0 ± 5	90	Maximum thrust
4	Flange down	0 ± 5	99	Maximum thrust

TABLE 10-2. BLADDER TESTS PRIOR TO EXPULSION

Bladder	Vibration	Exposure, hours	Permeation	Propellant Used in Expulsions
1	None	2160 in Genesolv D; 96 in oxidizer	None	Oxidizer
2	None	2160 in isopropyl alcohol; 144 in fuel	None	Fuel
3A	FAT and TAT with Genesolv D	640 in oxidizer	5 tests	Oxidizer
4B	None	570 in fuel	2 tests	Fuel
5	None	1400 in oxidizer	5 tests	Oxidizer
6	None	360 in oxidizer	None	Oxidizer
6A	None	870 in oxidizer	3 tests	Oxidizer
7	None	360 in fuel	None	Fuel

TABLE 10-3. EXPULSION TEST DATA

Bladder	Average Temperature, °F	Propellant	Applied Helium Pressure, psig	Tank Orientation	Quantity Expelled, pounds	Pressure Drop, psi*	Flow Rate lb/sec	Percent Expelled	Bladder Leak Rate, cc/hr
1	105	Oxidizer	746	Flange up	31.7	5	0.22	90	Zero
	79		733	Flange up	31.8	5	0.22	90	Zero
	1		735	Flange up	31.7	5	0.23	90	66,000
2	103	Fuel	717	Flange up	21.7	4	0.16	90	8
	70		718	Flange up	21.6	4	0.16	90	22
	-1		715	Flange up	21.6	8	0.15	90	57
	3		718	Flange down	24.1	7	0.16	99	160,000
3A	105	Oxidizer	750	Flange up	28.0	5	0.23	90	>15,000
4B	102	Fuel	750	Flange up	19.0	4	0.18	90	–
	72		714	Flange up	21.7	5	0.16	90	–
	2		687	Flange up	21.7	7	0.13	90	–
	4		661	Flange down	24.0	8	0.14	99	360,000
5	100	Oxidizer	750	Flange up	27.7	5	0.14	90	>15,000
6	71	Oxidizer	736	Flange up	32.2	6	0.22	90	–
	0		755	Flange up	31.5	8	0.25	90	39,000
6A	104	Oxidizer	740	Flange up	27.7	6	0.22	90	–
	75		729	Flange up	32.0	5	0.22	90	–
	-2		724	Flange up	35.0	7	0.22	99	32,000
7	72	Fuel	748	Flange up	21.7	3	0.13	90	–
	2		746	Flange up	21.6	8	0.14	90	–
	99		732	Flange up	21.6	3	0.12	90	–
	-3		741	Flange down	23.5	7	0.14	99	Zero
	20		759	Flange down	23.6	4	0.11	99	40,000

*Pressurant inlet minus propellant exit.

99 percent expulsion, bladder 2 successfully completed the series of four expulsion tests. The external and internal appearances of this bladder were good, with virtually no blisters or delamination evident.

Bladder 3A

One 100°F, 90 percent expulsion was conducted on bladder 3A. Upon attempting to reload, oxidizer came out the gas port in copious amounts. The bladder was then purged and removed from the tank. Figures 10-4 and 10-5 give external and internal views of this bladder. The foil tearing and delamination shown are considered to have been caused, for the most part, by the vibration tests performed on the bladder. The vibration damage was such that the bladder was able to perform only one expulsion before severe leakage occurred along several of the bad foil cracks in the nipple hemisphere.

Bladder 4B

Bladder 4B completed the entire expulsion series, after which an extreme leak rate was measured. Inspection showed a 1-inch long tear in the section of the bladder which collapses around the standpipe support. This tear was nearly identical to that which caused the bladder 2 failure. Figure 10-3 shows the tear near the nipple. The failure must have occurred after 99 percent of the fuel had been expelled. In spite of the failure, this bladder met all expulsion test series requirements. Only moderate foil cracking was evident, and there were a few areas where the foil had pulled away from the TFE layer (less than 1/8 square inch). Several large blisters (up to 3 square inches) were visible inside the bladder.

Bladder 5

Bladder 5 completed only one 90 percent expulsion at 100°F. Upon attempting to reload for the second expulsion, oxidizer was observed leaking from the standpipe seal. The bladder was purged and removed from the tank for examination. Figure 10-6 is a closeup photograph of the standpipe seal area. Numerous small cracks were present in the vicinity of the seal backup rings, along with several rather sizeable holes in the O-ring area. It is noted that this bladder was exposed to oxidizer for about 1400 hours, and to approximately 25 pressure-vent cycles during permeation, as well as five loading operations. The oxidizer exposure period is roughly four times that normally experienced during the prelaunch period plus the mission.

The extended storage period, plus the 25 pressure-vent cycles, represents a rather extreme test, perhaps especially so for the seal area. No other failures of exactly this type occurred; however, the circumferential tear of bladder 1 occurred at the same location, and it is noteworthy that this bladder had been subjected to a 2160-hour exposure to Genesolv D.

The general appearance of bladder 5 was good, with only moderate foil cracking noted and very little foil pull-away or delamination evident (four areas less than 1/4 square inch). Figure 10-7 is a back-lighted photograph of the bladder interior.

Bladder 6

Bladder 6 was subjected to expulsion tests after a 360-hour oxidizer storage period. After the second expulsion, large quantities of oxidizer vapor escaped from the gas port. An examination of the bladder revealed that the nipple had split circumferentially near the tip, with the split comprising about 50 percent of the circumference. No other bladder failed in this fashion, and no similar failures of all-Teflon bladders are known. Viewing the bladder internally showed moderate foil cracking and two blisters about 1 inch in diameter. Externally, a few small (1/4 by 1/2 inch) areas where the foil had delaminated and several blisters of about 1/2 inch in diameter were present. One foil pull-away area about 1 square inch had occurred.

Bladder 6A

Bladder 6A completed three of the intended four expulsion cycles before developing a severe leak. Because of a leak in one of the fittings downstream of the standpipe, the intended 90 percent expulsion became instead a 98.3 percent expulsion. After removing the bladder from the tank, leakage was found to be coming primarily from foil cracks in the nipple hemisphere. Figures 10-8 and 10-9 are external and internal views of this bladder. Rather severe foil cracking in the nipple hemisphere is evident. Externally, the condition of this bladder was unique in that virtually the entire outer FEP layer had delaminated from the foil and, in essence, comprised a sheath around the foil but was not attached to it. The delamination occurred between the basic foil and the TFE primer, with the primer sticking to the outer FEP layer. In several areas the foil was torn (approximately 1/2 square inch area) and, in some cases, had stuck to the FEP layer.

This bladder had been exposed to oxidizer for 870 hours, and had been subjected to three pressure-vent cycles in addition to the three expulsion cycles. It is noteworthy that, except for the flange area, the more rigorously tested bladder 5 had a much better general appearance than 6A. These two bladders were manufactured from different foil lots.

Bladder 7

Bladder 7 was subjected to only a 15-day fuel storage period prior to expulsion tests. At the conclusion of the standard series of four expulsions, the bladder still showed zero leakage. Therefore, an additional 99 percent expulsion at 20°F was conducted, after which the bladder indicated an extreme leak rate. Examination of the bladder showed the leak source to be a pinhole in the flange hemisphere. The external appearance of this bladder was the best of any bladder tested. Internal examination (Figure 10-10) revealed only minor foil creasing plus several pin holes and a few small torn areas, which is somewhat remarkable in view of the fact that this bladder was subjected to more expulsion tests than any other. It was the only bladder to show an acceptable leak rate after a 99 percent expulsion.

Figure 10-4. Bladder 3A Exterior
(Photo A17223)

Figure 10-5. Bladder 3A Interior
(Photo A17216)

Figure 10-6. Bladder 5 Seal Area
(Photo A17226)

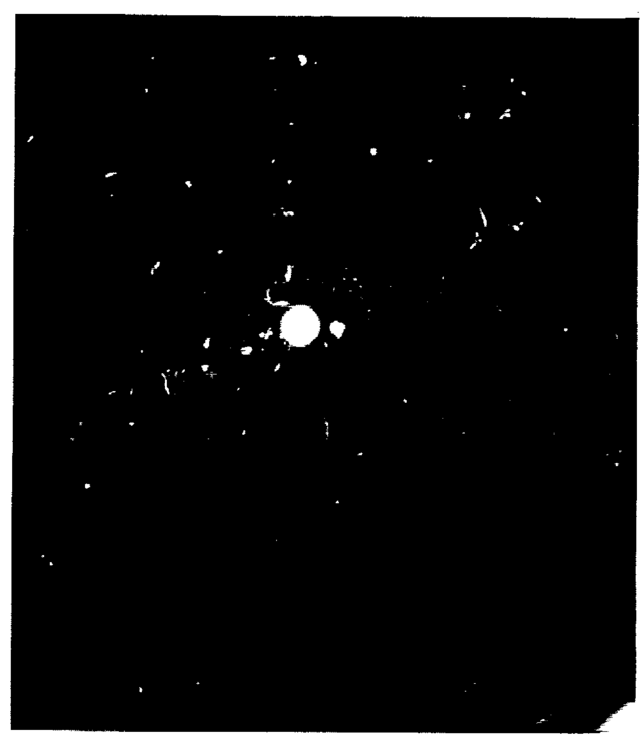

Figure 10-7. Bladder 5 Interior
(Photo A17217)

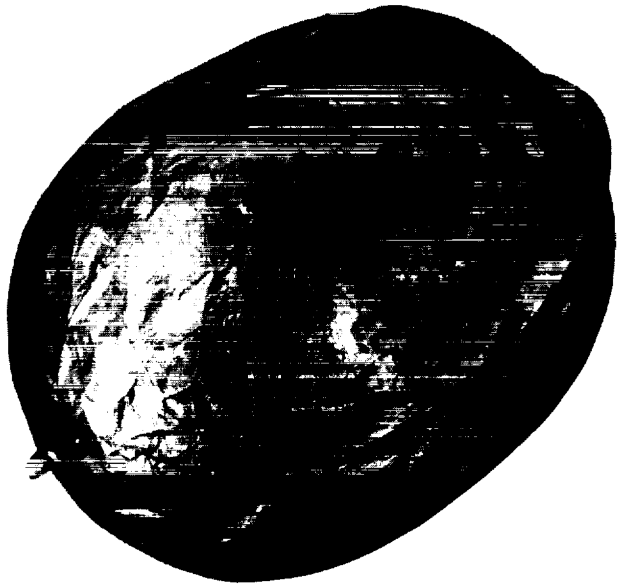

Figure 10-8. Bladder 6A Exterior
(Photo A17222)

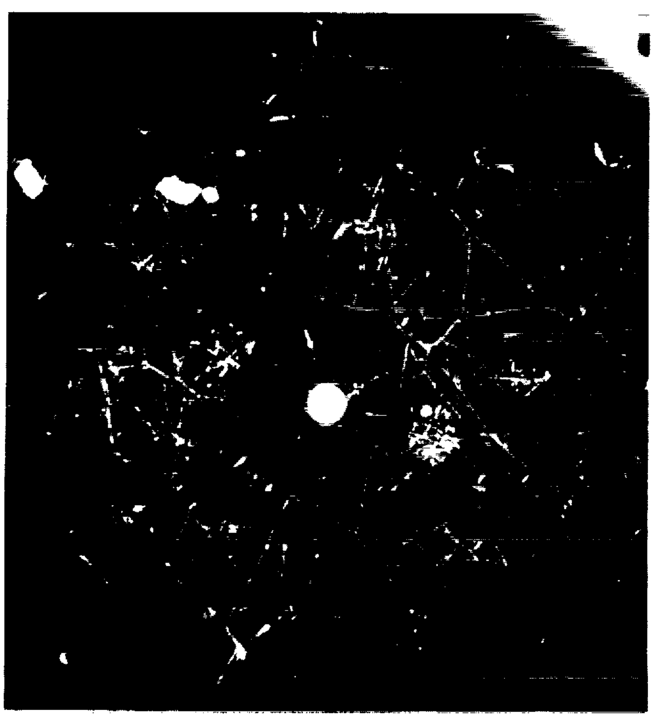

Figure 10-9. Bladder 6A Interior
(Photo A17212)

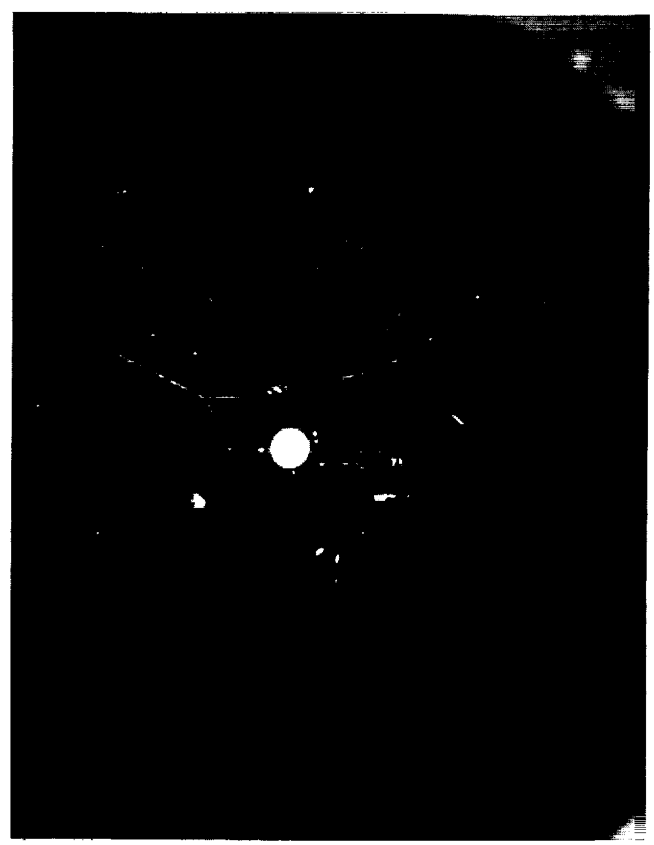

Figure 10-10. Bladder 7 Interior
(Photo A17213)

One of the most significant results of the expulsion tests is that all three fuel bladders completed the standard series of four expulsions, whereas only two of the five oxidizer bladders completed even three expulsions without developing a bad leak. It is apparent that oxidizer is more detrimental to metallized bladders than fuel, although it is noted in this context that the oxidizer bladders were subjected, as a group, to longer storage periods and had undergone more permeation testing than had fuel bladders.

Another striking fact is that only three of the bladders failed in a conventional mode, i. e. , from a pinhole or from severe creases (bladders 3A, 6A, and 7). The other failures were by large tears near the standpipe support (bladders 2 and 4B, both fuel bladders, and both during 99 percent expulsions), or by splits and tears in the nipple or neck area (bladders 1, 5, and 6). The decreased tensile strength and higher modulus of elasticity of the metallized material, as opposed to all-Teflon material, could account for the tears near the standpipe support, since this is a region where considerable bladder flexing occurs during a 99 percent expulsion. The splits and tears in the nipple and neck area would seem to have another cause, since these failures occurred in all-Teflon areas of the bladder. The Teflon in metallized bladders has a slightly brown tinge due to residual amounts of wetting agent present in the FEP. These residuals are not completely baked out because Dilectrix decreases the normal cure time for the FEP outer layers by about 50 percent in attempting to minimize blisters. Dilectrix personnel assert that material properties are not adversely affected by this procedure. However, it would appear that a very careful evaluation of the effects of residual wetting agents on the properties of the all-Teflon material should be included in any future evaluation of this type bladder.

11. CONCLUSIONS

The tests and analyses carried out in the several phases of the metallized bladder evaluation program lead to the following conclusions:

1) The fabrication technique for double-dip foil bladders (primer plus FEP dip) has not been perfected to the point where bladders having satisfactory and reproducible physical characteristics can be produced.

2) Surveyor type approval test vibration levels are too severe for the metallized bladders. All four bladders vibrated in this program sustained moderate to severe damage, and had markedly increased helium leak rates.

3) Metallized bladder material reduces both MON-10 and MMH-hydrate permeation by more than an order of magnitude compared to all-Teflon material.

4) Because of its greater solubility in oxidizer, nitrogen offers no advantages over helium as a pad pressurant for Surveyor.

5) Under ideal conditions (no FAT vibration or extended propellant storage), the use of metallized bladders could reduce the oxidizer helium saturation level to about 50 percent from the current 100 percent experienced with all-Teflon bladders. Metallized bladders subjected to vibration or to modest handling plus extended propellant exposure would offer virtually no improvement over all-Teflon bladders.

6) Reduction of the oxidizer helium saturation level from 100 to 50 percent results in only a modest improvement in spacecraft phase margin and no improvement in gain margin.

7) The expulsion life of metallized bladders is reduced over that of all-Teflon bladders. Metallized bladders tested with oxidizer evidenced greater deterioration and shorter expulsion life than those tested with fuel.

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APPENDIX A. EXCERPT FROM HUGHES AIRCRAFT COMPANY ENGINEERING RECORD NO. 199, "METAL FOIL BLADDER TEST, SURVEYOR VERNIER PROPULSION SYSTEM"

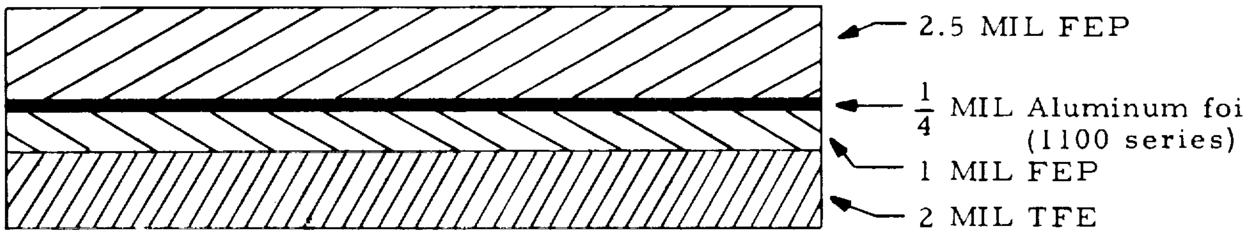
INTRODUCTION

1.1 Purpose – The purpose of this test was to evaluate the capabilities of a metal (aluminum foil) and teflon bladder[1] and determine how it compares with a "standard" TFE-FEP[2] all-teflon bladder presently used as a positive expulsive device in a propellant tank for the Surveyor vernier propulsion system.

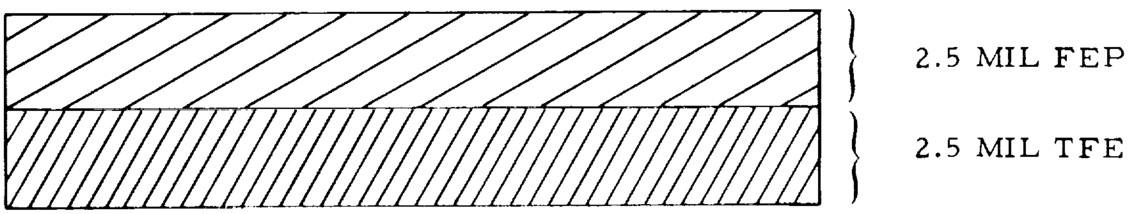
1.2 Bladder Description

Name of Part	Metal Barrier Bladder (P/N 287149, S/N's 545 and 546)
Manufacturer	Dilectrix Corporation
Date of Purchase Order	24 May 1965
Quantity of Items Tested	Two units and sample material out of the same production run.

1. Laminations of tetrafluoroethylene, aluminum foil, and fluorinated ethylene propylene
2. Laminations of tetrafluoroethylene and fluorinated ethylene propylene



Metal Foil Bladder
(Cross Section of Material Thickness)



All Teflon Bladder
(Cross Section of Material Thickness)

2.0 SUMMARY

Flex life and permeability (both helium and propellant) were two major areas of interest under investigation in the comparison test of the "metal foil bladder" and "standard bladder". Two metal foil bladders were subjected to the flex cycle test. One bladder, after soaking in mixed oxides of nitrogen, i.e., 90% nitrogen tetroxide, 10% nitric oxide (MON-10) oxidizer for 38 days, was subjected to ten expulsion cycles at 90% efficiency before developing one pin hole. The other bladder was filled with water and expelled three times with efficiencies of 99.7, 99.7, and 99.8 percent. This bladder did not experience any pin holes or other forms of leak paths.

The helium pressurant gas permeated the metal foil bladder and went into solution with the oxidizer at a rate of .00265 pounds in 72 hours, which compares with .00265 pounds in 2.5 hours for the standard all-teflon bladder.

The metal foil bladders resistance to nitrogen tetroxide (N_2O_4) permeation is excellent. The permeation rate (an average) for the standard teflon bladder is five (MG) per square inch per hour, covering a 24 hour period, whereas no N_2O_4 was detectable in a 48 hour period using the metal foil bladder. It is expected that the oxidizer (N_2O_4) permeation rate would be negligible over a much longer period of time.

CONCLUSIONS

1. Excellent resistance to nitrogen tetroxide (N_2O_4) liquid and vapor permeation is experienced with the use of a metal foil bladder.

2. A metal foil bladder, when used as a positive expulsive device in a propellant tank assembly, offers improved pressurant gas permeation when compared to the conventional all-teflon bladder. This improved rate of gas transmissibility is especially good for short storage times. After a storage time of 72 hours, the metal foil bladder permeated the same amount of helium gas as the all-teflon bladder did in 2.5 hours. The amount of helium gas that has permeated through the metal foil bladder approaches the same amount through the all-teflon bladder in approximately 150 hours under identical testing conditions.

3. The flex life of the metal foil bladder is very good and compares favorably with the flex life of the all-teflon bladder.

APPENDIX B. FLIGHT ACCEPTANCE AND TYPE APPROVAL TEST VIBRATION REQUIREMENTS

FLIGHT APPROVAL TESTING

The following are requirements for flight acceptance test vibration: Two sweeps, one increasing and one decreasing, are made at the rate of two octaves per minute along each of three axes, one which is parallel to the vehicle thrust axis and two which are critical orthogonal directions perpendicular to the thrust axis. The applied vibratory load is 2.7 ± 0.27 g zero-to-peak from 10 to 1500 cps in the thrust axis. A control accelerometer limits the acceleration at the equator of the tank to 8.0 g. For the other two axes, the applied vibratory load is 2.7 ± 0.27 g zero-to-peak from 10 to 60 cps, 5.3 ± 0.53 g zero-to-peak from 60 to 80 cps, 8.0 ± 0.8 g zero-to-peak from 80 to 100 cps, 5.3 ± 0.53 g zero-to-peak from 100 to 125 cps, and 2.7 ± 0.27 g zero-to-peak from 125 to 1500 cps. A control accelerometer limits the acceleration at the equator of the tank to 2.7 g. All vibration tests are conducted with a helium pressure of 300 ± 10 psig applied to the bladder.

TYPE APPROVAL TESTING

The following are requirements for type approval test vibration: Two sweeps, one increasing and one decreasing, are made at the rate of one octave per minute along each of the three vibration axes. For the thrust axis, the applied sinusoidal vibratory load is 4.0 g zero-to-peak from 10 to 100 cps, and 4.38 g zero-to-peak from 100 to 1500 cps. The sinusoidal load is combined with a random component of 6.75 ± 0.7 g rms, band limited between 100 and 1500 cps during the sinusoidal frequency sweeps from 100 to 1500 cps and 1500 to 100 cps. A control accelerometer limits the acceleration at the equator of the tank to 12 g. For the other two axes, the sinusoidal component is identical to flight acceptance testing except the g levels are increased by 50 percent. This sinusoidal component is combined with a random component identical to that for the thrust axis. A control accelerometer limits the acceleration at the tank equator to 4 g. The bladder is pressurized to 300 ± 10 psig with helium during all type approval vibration tests.

APPENDIX C. HELIUM LEAK RATE CHECK

Helium leak rate checks of metallized bladders were accomplished as follows:

1) With 4 psig helium pressure applied to the bladder interior, the gas side of the bladder was evacuated to 25 inches of mercury vacuum or better and maintained in this condition for 15 minutes.

2) The vacuum was removed, and a 5-minute stabilization period allowed.

3) A bubbleometer was attached to the gas port, and the transit time of a soap bubble through a 1-cc volume was observed. Three readings were taken 5 minutes apart and averaged. The leak rate is expressed in cc/hr.

APPENDIX D. SAMPLE CALCULATION OF GAS PERMEATION

The following is a sample calculation for bladder 5, test 3:

Net helium pressure = 31.0 psi

Ullage volume = 148 cubic inches

Temperature = 530°R

Gas constant = 386 ft-lb/lb°R

Weight of MON-10 = 31 pounds

Solubility coefficient = 1.95×10^{-7} lb/lb/psi

Weight of helium permeated $= \dfrac{31 \times 148}{386 \times 530 \times 12}$ (gas in ullage space)

$+ 31 \times 31 \times 1.95 \times 10^{-7}$
(gas remaining in MON-10)

= 0.00206 pound

Helium concentration $= 0.00206 \text{ pound} \times \dfrac{27.4 \times 10^{5} \text{ std cc/lb}}{31 \text{ pound} \times 454 \dfrac{\text{grams}}{\text{pounds}}}$

= 0.41 std cc/gram

APPENDIX E. DESCRIPTION OF JPL METHOD FOR DETERMINING DISSOLVED GASES IN FUELS AND OXIDIZERS

Figure E-1 is a schematic of the apparatus used for determing the amount of dissolved gases in fuels and oxidizers.

The sample in which dissolved gases are to be determined is delivered in a stainless sample holder shown in the figure. The sample holder has three valves: A, B, and C.

It is imperative that the sample delivered be handled in a way to prevent the loss of any dissolved gas or the introduction of air. The sample delivered originally occupied the volume between A and B, but in order to provide some ullage, valve B was opened to allow the sample to expand into the previously evacuated volume between B and C. The sample container is delivered with valves A and C securely closed, but valve B open.

PROCEDURE FOR DETERMINING DISSOLVED GASES

The sample container is connected to a weighed 100-milliliter flask and to the pumping system as shown in the schematic. By proper stopcock manipulations, the system is evacuated up to valve A on the sample container. This includes the gas sample bottle, the manometer, the Toepler pump, the liquid nitrogen trap, and the 100-milliliter flask. The evacuation is continued until the pressure drops to the 10^{-6} Torr region. The ready attainment of this pressure is taken as an indication of a tight system.

With the pressure in the 10^{-6} Torr region, valve D is closed and valve A is opened, allowing the sample to run into the weighed 100-milliliter flask. The sample is frozen in liquid nitrogen.

When the liquid nitrogen surrounding the 100-milliliter flask has become quiescent, indicating a completely frozen sample, mercury is driven up into the manometer legs, and the manometer and Toepler pump system are isolated from the high vacuum system. The automatic Toepler pump is started up, and the gases in the sample container and the 100-milliliter flask are pumped through the liquid nitrogen trap into the manometer measuring system. For small gas volumes, the 75-cc volume is isolated, giving about

25 cc in the measuring system. The Toepler pumping system is operated until the mercury level in the right manometer leg becomes stationary.

Valves A, D, and E are closed, and contents of the 100-milliliter flask thawed, stirred, and refrozen. When D and E are opened, any gas released is pumped off. Valve A is not opened because the gas in the sample container was previously pumped off. Several millimeters of additional pressure are usually realized after thawing and refreezing.

When the mercury in the right manometer leg has again become stationary, the mercury in the Toepler pump is brought up to a reference mark located above the left-hand check valve. The stopcock above the mercury reservoir is then closed. The mercury in the manometer is brought down to its fixed reference point in the right leg, and the mercury height in the left leg is measured by means of a cathotometer. By knowing the pressure, volume, and temperature, the volume at 0°C and 760-millimeter pressure can be calculated.

With the manometric measurement finished, the gas sample bottle is isolated from the high vacuum system and the collected gas allowed to enter the gas sample bottle. The sampled gas is analyzed by mass spectrometry. The weight of sample is determined by reweighing the 100-milliliter flask after disconnecting and warming.

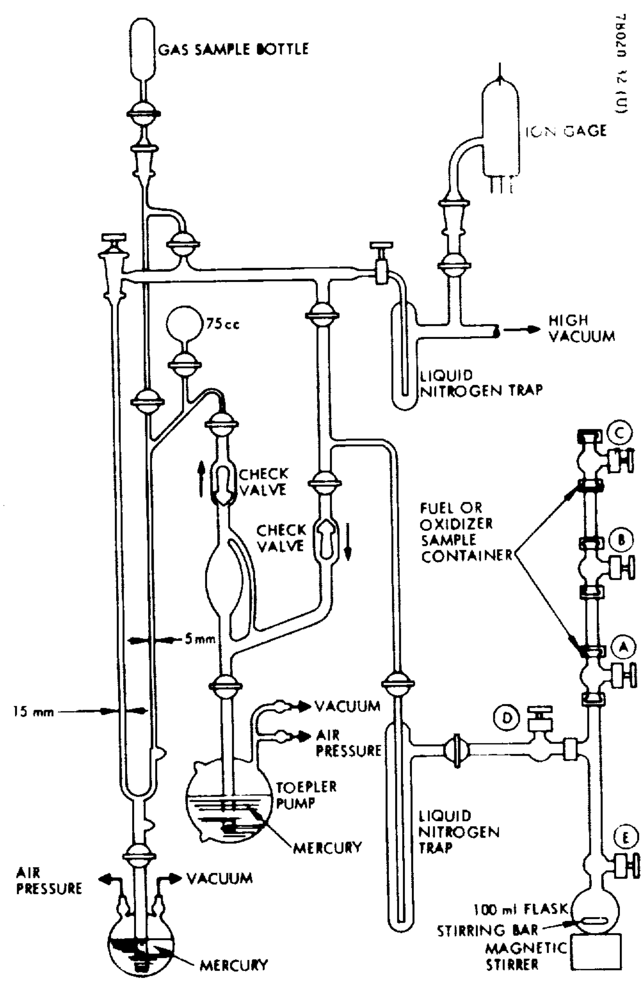


Figure E-1. System for Pumping, Collecting, and Measuring Dissolved Gases